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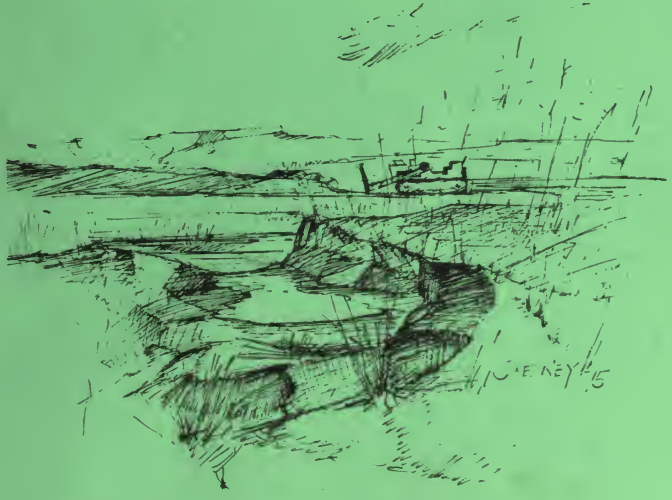

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VOLUME 3

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- Order information
- Acknowledgements.

Editor: Dr. Wilson F. Clark
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Billings, Montana

VEGETATIONAL RESPONSES BY SUBSTRATE, GRADIENT, AND ASPECT ON A TWELVE ACRE TEST PLOT IN THE BULL MOUNTAINS

Gary L. Dusek*

INTRODUCTION

As a result of renewed interest in mining, particularly surface mining, and exporting coal from seams underlying the Bull Mountains, a wildlife ecology study was initiated in that locality by the Montana Department of Fish and Game during January, 1972. Partial funding for the project is provided by Consolidation Coal Company (Consol). The principal objectives for the study are: 1) to assess the impact, or potential impact, of surface mining upon the wildlife resource in the Bull Mountains; 2) to ensure that wildlife habitat values receive full recognition in any mining or reclamation effort; and 3) to investigate possible modifications or innovations in the reclamation process to avoid unnecessary loss of wildlife habitat.

At the present time, comprehensive research of reclamation proceedures is being conducted near Colstrip and Decker (9) by the Montana Agricultural Experiment Station (MAES). This paper, which results from a portion of the wildlife ecology study in the Bull Mountains, pertains to the changes in floral cover and composition during the three growing seasons following mining, grading and seeding at Consol's test pit, located approximately 4.5 miles southeast of Roundup, Montana.

A permit for mining and reclamation was awarded to Consol during the summer of 1971 under the "Montana Open Cut or Strip Mine Reclamation Act," enacted by the State legislature during the 1971 session. During August, 1971, overburden was stripped from approximately six acres of the Mammoth-Rehder coal seam, although the total acreage affected included about 12 acres. Preparation of the seed bed and seeding were conducted by the MAES during the first half of May, 1972. The purpose of the project was twofold: to test the 39,000 tons of coal from the pit to determine burning qualities; and, to use the site as a test of reclamation proceedures. My envolvement has included gathering vegetational data on this site during the growing seasons of 1972-74.

STUDY AREA

The Bull Mountains are located south of the Musselshell River, primarily in Musselshell County. Elevations range from near 3000 feet along the Musselshell River to 4700 feet on the upper plateau that forms the divide between the Musselshell and Yellowstone drainages. Fort Union sandstones are exposed throughout much of the area. Principal coal beds include the Roundup, Carpenter-McCleary, and Mammoth-Rehder.

The climate has been described as semiarid (6) characterized

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by great temperature extremes and relatively low humidity. Monthly climatological data for the years 1972-74 (10, 11 and 12) were gathered from that recorded at Roundup (Table 1). Total annual precipitation averages 10.93 inches, of which approximately half is received during May, June, and July. The years 1972-74 each received above normal precipitation, although that received during the May-July period was below normal each year. That which fell during April and August of each of the three years was far above Normal (Table 1).

Vegetation of the Bull Mountains is characterized primarily by ponderosa pine and grassland types (5). Some of the drainage bottoms and gentle terrain are under cultivation, although livestock production is the principal industry and has been since early settlement. Logging and the lumber industry have recently become an important part of the local economy. Mule deer, elk, and Merriam's turkey are the principal game animals occurring in the Bull Mountains, although pronghorn, white-tailed deer, and sharp-tailed grouse occur there also.

The 12 acre test pit area, which occurrs at approximately 3600 feet above sea level (Fig. 1), consists of a highwall area, a pit area, and two spoils ridges just west of and adjacent to the pit (Fig. 2). The ridges include slopes varying in gradient from 1.25:1 to those that are nearly level. Parts of the ridges were covered with a layer of topsoil while the remainder were covered with various substrata which included sandstone, shale and a mixture of the two. The entire area was broadcast seeded with one basic mixture and fertilized shortly after with a chemical mixture.

PROCEDURES

Trends in floral composition and cover were monitored at 15 permanent stations established on the disturbed area during 1972. Two additional stations were established during both 1973 and 1974 for a total of 17 and 19 during the two respective years. Stations were identified by a white and red metal stake with a numbered metal tag attached. During early July of each of the three years vegetational composition was quantitatively sampled by a canopy coverage method (2) whereby 20 2x5 decimeter plots were sampled at each station along a 100 ft. transect line. Transect lines were placed parallel to the contour when practicable and the station marker was used as midpoint. Seven coverage classes were used to estimate the percent the bare ground, rock, litter, and canopy coverage by forage class and species. In addition to canopy coverage, percent occurrence among plots and sites was calculated.

During March, 1974, a pellet group analysis (8) was used to determine relative use among soil types by mule deer. This was facilitated by counting the number of pellet groups within two feet on either side of a 100 ft. transect line at each of 17 permanent vegetational analysis stations, thereby allowing a linear plot of 400 sq. ft. to be sampled at each station. Pellet groups/400 sq. ft. were coverted to pellet groups /acre.

Table 1. Climatological data for Roundup, Montana for the years 1972-74.

Month	Temperature Ave.	Temperature Dep. from Normal	Precipitation Total	Precipitation Dep. from Normal
January:				
1972	17.3	- 6.4	.58	.29
1973	26.7	.2	.06	- .26
1974	24.9	1.7	tr	- .35
February:				
1972	29.5	3.0	.27	- .05
1973	26.7	.2	tr	- .30
1974	35.8	6.6	tr	- .30
March:				
1972	43.0	9.3	.29	- .27
1973	36.4	2.7	.29	- .27
1974	--	--	.17	- .29
April:				
1972	46.3	.6	1.64	.89
1973	42.4	- 3.3	1.18	.43
1974	50.6	4.7	1.40	.57
May:				
1972	56.0	.2	3.00	1.20
1973	55.7	.1	1.65	- .15
1974	--	--	2.65	.55
June:				
1972	68.4	5.2	.61	- 1.92
1973	66.3	3.1	2.19	- .34
1974	67.5	4.6	1.13	- 1.71
July:				
1972	68.0	- 4.1	1.50	.29
1973	71.1	- 1.0	.62	- .59
1974	--	--	.22	- 1.04
August:				
1972	71.4	1.6	3.07	2.09
1973	71.9	2.1	1.73	.76
1974	65.1	- 5.0	3.00	1.91
September:				
1972	52.3	- 7.3	.81	- .15
1973	--	--	1.86	.90
1974	57.0	- 2.1	2.22	1.11
October:				
1972	41.8	- 7.4	.91	.09
1973	49.3	.1	2.06	1.24
1974	51.3	1.6	1.18	.57
November:				
1972	31.7	- 4.4	tr	- .36
1973	30.1	- 6.0	.46	.10
1974	35.0	- 1.1	.14	- .22
December:				
1972	15.8	-13.2	.53	.17
1973	32.2	3.2	.93	.57
1974	--	--	.08	- .25

Figure 1. Spoils ridges at Consol's test pit during July, 1974.

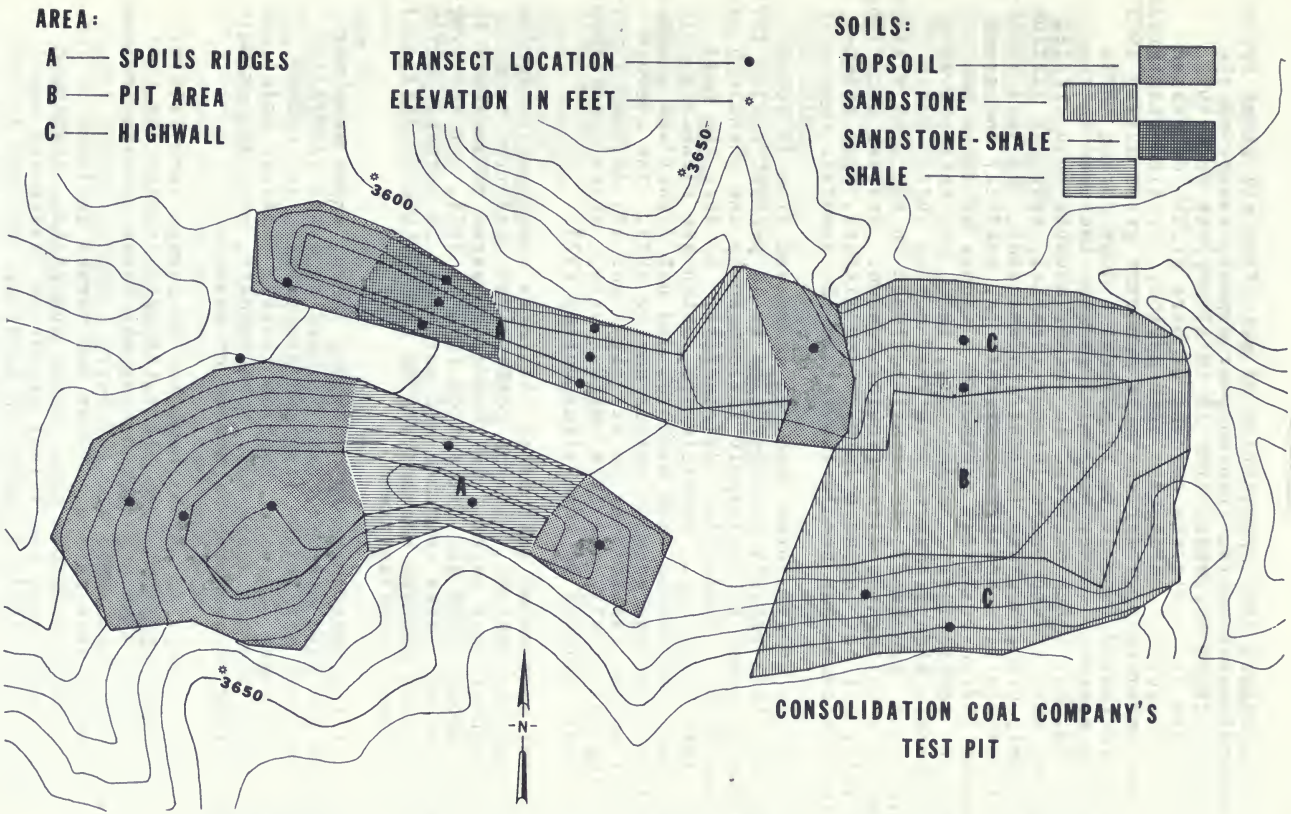

Figure 2. Consol's test pit area showing soil mixtures and the location of 19 permanent vegetational transects.

Vegetation

RESULTS

As determined from examination of data from all sites by year, regardless of soils, gradient, or aspect, canopy of the grass forage class increased from 12 to 51 percent from 1972 to 1974 (Table 2), while the percent of bare ground decreased from 87 to 57 percent during the same period. Crested wheatgrass (*Agropyron cristatum*), by far the most abundant grass during 1973 and 1974, increased from 10 to 27 percent canopy during those two growing seasons. Other perennial grasses included in the seed mixture, but which occurred in lesser amounts than crested wheatgrass, were smooth brome (*Bromus inermis*), ryegrass (*Lolium multiflorum*), orchard grass (*Dactylis glomerata*), and tall wheatgrass (*A. elongata*). Western wheatgrass (*A. smithii*) and green needlegrass (*Stipa viridula*) exhibited a canopy of three and one percent, respectively, during July, 1973, and both showed a slight decrease when transects were read during 1974. Sudan grass (*Sorghum sudanense*), an annual included in the seed mixture, occurred only during the first growing season. Grasses occurring on the site, but not included in the seed mixture, were cheatgrass (*B. tectorum*) and needle-and-thread (*S. comata*).

The canopy of all forbs combined increased from 10 to 31 percent from 1972 to 1973 but decreased to 14 percent during 1974. This trend appeared to be largely influenced by the phenology of yellow sweetclover (*Melilotus officinalis*), by far, the most abundant forb (Table 2). Sweetclovers, which are biennials (1) and were included in the seed mixture, did not flower and produce seed until the second growing season during 1973. The average canopy for yellow sweetclover on all sites was 10, 28, and 7 percent during 1972, 1973, and 1974 respectively. White sweetclover (*M. alba*) was evident on some sites during 1973.

Several species of saltbushes (*Atriplex spp.*), which included forbs and half-shrubs, will be collectively referred to as forbs throughout this paper. Saltbushes appeared to increase in occurrence among plots and sites from 1972 to 1974, but the average canopy on all sites combined did not reach .5 percent during any of the three growing seasons (Table 2). Milkvetch (*Astragalus spp.*) exhibited a similar trend.

Some of the more commonly occurring forbs, which were not included in the seed mixture, were fringed sagewort (*Artemisia frigida*), western sticktight (*Lappula redowskii*), and common salsify (*Tragopogon dubius*). Russian thistle (*Salsola kali*) and summer cypress (*Kochia scoparia*), both annuals, occurred primarily where other vegetation was sparse or absent.

The mean canopy of shrubs appeared to change very little, never reaching .5 percent when all sites were averaged by year (Table 2). Those that occurred during all three growing seasons were wild rose (*Rosa spp.*) and snowberry (*Symphoricarpos spp.*), neither of which were seeded. Trees and shrubs included in the seed mixture were ponderosa pine (*Pinus ponderosa*), skunkbush sumac (*Rhus trilobata*), and silver sagebrush (*Artemisia cana*) (4). During July, 1972, a skunkbush seedling occurred in one of the 300 plots. No skunkbush seedlings were observed the following two years and no seedlings of ponderosa pine or silver sagebrush were observed.

Table 2. Constancy, canopy coverage and frequency of low-growing vegetation on spoils material as determined by examination of 20 2x5 decimeter plots on each of 15, 17 and 19 sites during 1972, 1973 and 1974, respectively, at Consolidation Coal Company's test pit

Taxa[1/]	1972 15 Sites	1973 17 Sites	1974 19 Sites
GRASSES:			
Agropyron cristatum*	--	76/10/ 45[2/]	95/27/ 68
Agropyron elongata*	--	--	79/ 4/ 22
Agropyron smithii*	--	70/ 3/ 23	74/ 1/ 9
Agropyron spp.*	--	59/ 1/ 10	68/ 1/ 7
Agropyron-Lolium spp.*	100/ 9/ 80	--	--
Bromus inermis*	--	88/ 7/ 39	100/ 8/ 46
Bromus tectorum	27/tr/ 3[3/]	82/ 4/ 19	84/ 6/ 29
Dactylis glomerata*	--	59/ 3/ 12	68/ 4/ 27
Lolium multiflorum*	--	76/ 4/ 25	53/ 4/ 19
Poa compressa*	--	12/tr/ 1	63/ 1/ 6
Sorghum sudanense*	60/ 3/ 24	--	--
Stipa comata	--	18/tr/ 1	5/tr/ 1
Stipa viridula*	--	24/tr/ 1	21/tr/ 1
Triticum spp.*	--	47/ 1/ 8	5/tr/ 1
Unidentified grasses	33/tr/ 3	12/tr/ 1	--
Total grasses	100/12/ 84	100/30/ 77	100/51/ 87
FORBS:			
Artemisia frigida	6/tr/ tr	12/tr/ 1	32/tr/ 4
Astragalus spp.*	6/tr/ tr	12/tr/ 1	26/tr/ 2
Atriplex spp.*	47/tr/ 4	24/tr/ 2	58/tr/ 4
CRUCIFERAE	6/tr/ tr	6/tr/ tr	32/ 1/ 3
Gaura coccinea	--	--	11/tr/ 1
Geum triflorum	27/tr/ 2	--	--
Kochia scoparia	--	24/tr/ 2	26/ 2/ 11
Lappula redowskii	13/tr/ 2	12/tr/ 1	21/tr/ 1
Melilotus alba*	--	47/ 1/ 4	--
Melilotus officinalis*	--	88/28/ 64	89/ 7/ 34
Melilotus spp.*	100/10/ 60	--	--
Psoralea esculenta	13/tr/ 1	--	--
Salsola kali	--	29/ 1/ 5	47/ 4/ 25
Tragopogon dubius	--	12/tr/ 1	11/tr/ 1
Unidentified forbs	20/tr/ 1	29/tr/ 2	11/tr/ 1
Total forbs	100/10/ 70	100/31/ 73	100/14/ 69
SHRUBS:			
Rosa spp.	6/tr/ tr	6/tr/ tr	5/tr/ tr
Symphoricarpos spp.	27/tr/ 3	18/tr/ 2	11/tr/ 1
Total shrubs	27/tr/ 3	24/tr/ 2	15/tr/ 1
Bare ground	100/87/100	100/77/100	100/57/ 99
Rock	100/18/ 80	100/18/ 69	100/17/ 66
Lying litter	--	65/12/ 51	95/22/ 72
Standing litter	--	6/tr/ tr	89/ 9/ 51

[1/] Includes those taxa that occur in at least one percent of the plots during at least one growing season or occur in during all years.

[2/] Constancy (percent occurrence among sites)/canopy coverage (percent of area covered)/frequency (percent occurrence among plots).

[3/] tr = trace (a value less than .5 percent).

* Included in the seed mixture at the test pit.

Soils

Topsoil and sandstone, combined, constituted approximately 70 percent of the disturbed area, while sandstone-shale and shale made up six and nine percent, respectively. The transect stations were placed accordingly.

Topsoiled portions, regardless of slope or exposure, exhibited the greatest increase between years and the greatest canopy during all years, of living vegetation, and subsequently, the greatest accumulation of residual vegetation (Fig. 3). This trend decreased progressively on sandstone, sandstone-shale, and shale, respectively. The general pattern discussed previously was exemplified by the topsoil and sandstone portions.

Ryegrass appeared to be more abundant on sandstone and sandstone-shale portions than on topsoil or shale (5). Russian thistle accounted for the bulk of forbs on shale soils during 1973 and 1974, compared to yellow sweetclover on topsoil and sandstone. Saltbushes occurred on all soils except shale during 1973 and 1974. Shrubs, including wild rose and snowberry, occurred only on topsoiled portions during all three years. This was perhaps a result of resprouting from roots or rhizomes that were in the topsoil when it was placed on the spoils.

Gradient

When data were combined according to gradient, regardless of substrate or aspect, sites having a medium gradient exhibited a greater canopy of living vegetation than did those that were nearly level or steep (Fig. 4). During July, 1974, bare ground averaged 72, 40, and 47 percent on steep, medium, and nearly level gradients.

Medium and nearly level gradients paralleled the yearly trend previously described for grasses and forbs. Russian thistle was the most abundant forb on the steep gradients as compared to yellow sweetclover on those that were medium or nearly level.

Aspect

Vegetational cover by exposure was evaluated only during the years of 1973 and 1974. Northerly and southerly exposures were compared, which included only sites having steep or medium gradients. As would be expected, northerly exposures exhibited the greatest canopy of living and residual vegetation (Fig. 5). This is perhaps due to the more xeric condition on southerly exposures which result from longer periods of direct sunlight throughout the year.

Relative Use by Mule Deer

Mule deer, the most widely distributed game animal in the Bull Mountains (4), have used the test pit area periodically since 1972. Their presence was determined either by direct observations or evidence of their presence such as tracks or pellet groups. Sharp-tailed grouse were observed on the disturbed area on two occasions during the summer of 1974, which is understandable since that species has been observed in the general vicinity

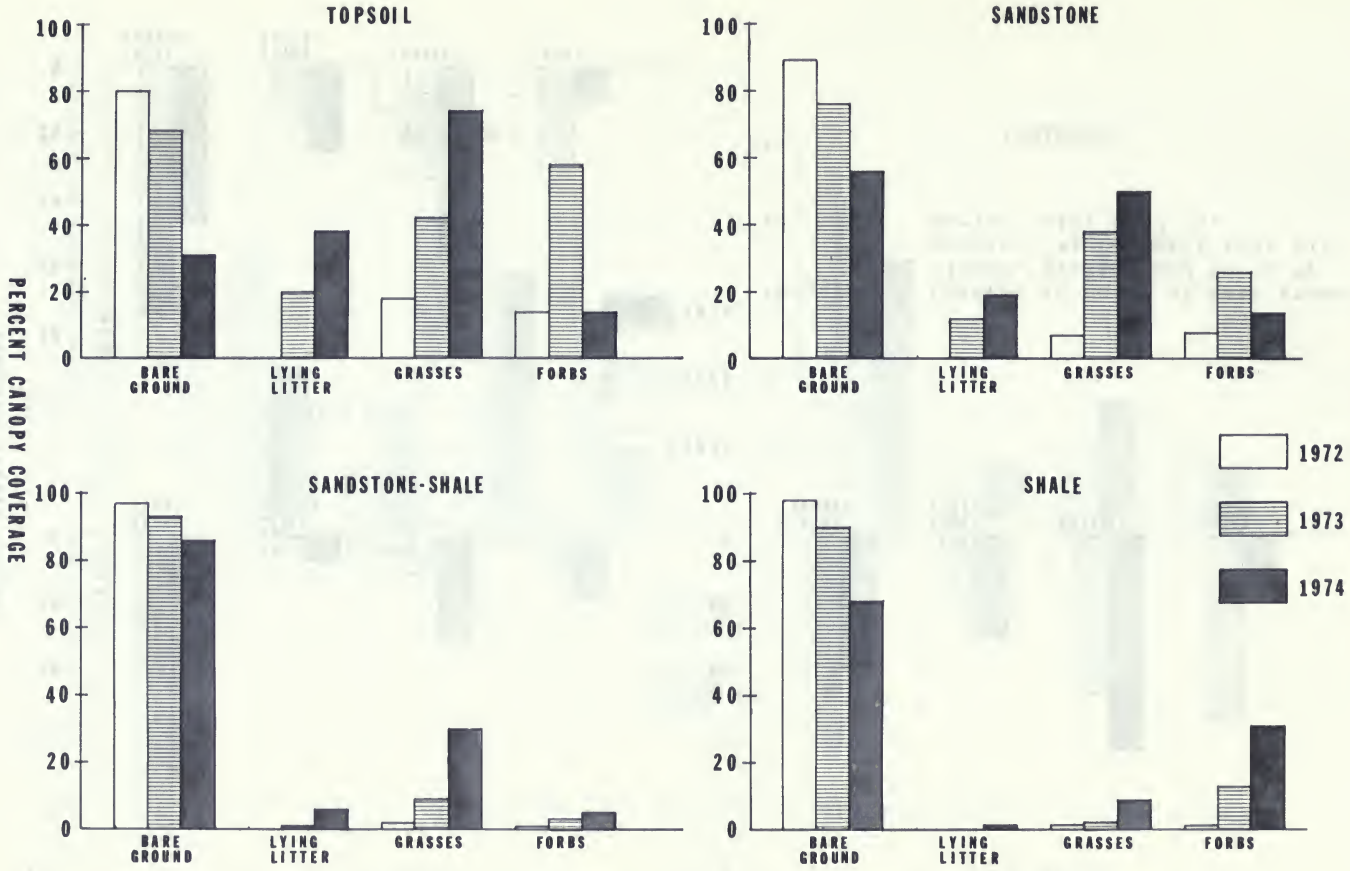

Figure 3. Changes in cover of bare ground, litter, grasses and forbs by substrate at Consol's test pit during July, 1972-74.

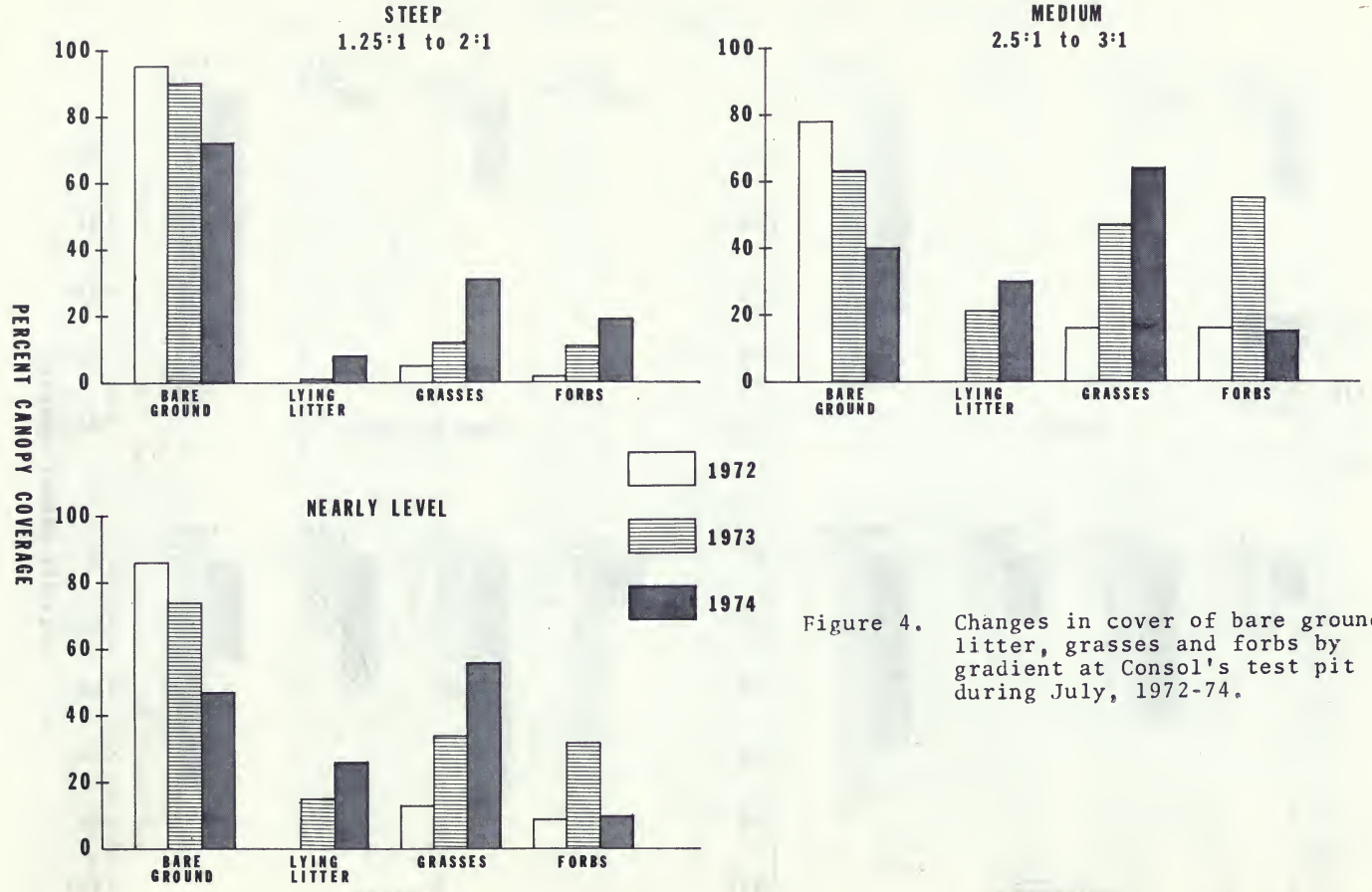

Figure 4. Changes in cover of bare ground, litter, grasses and forbs by gradient at Consol's test pit during July, 1972-74.

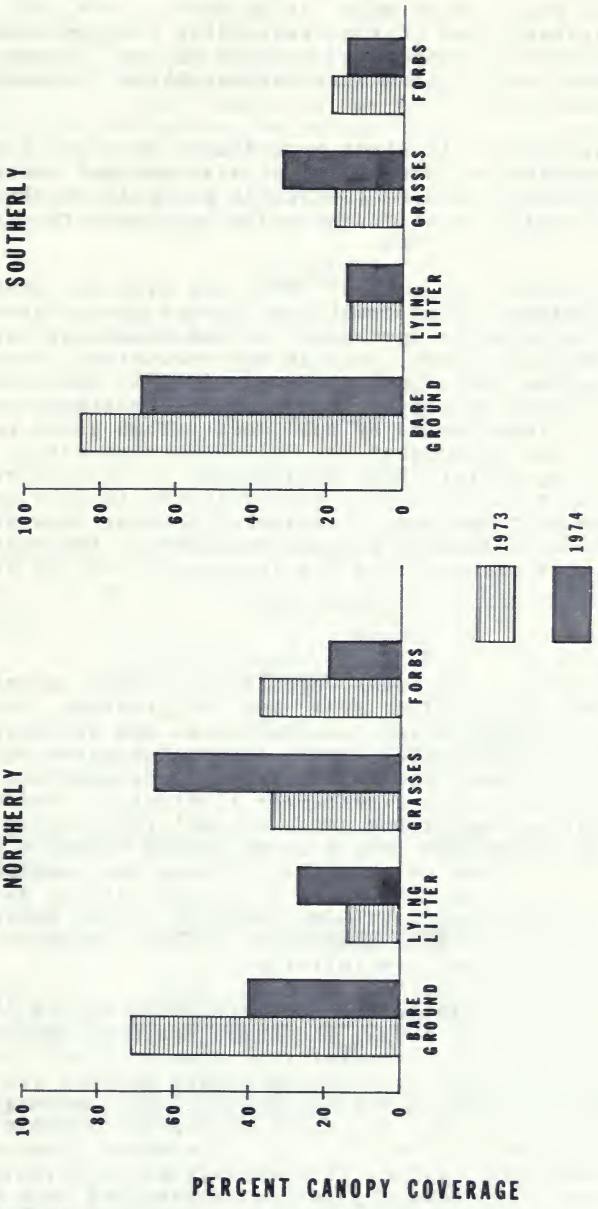

Figure 5. Changes in cover of bare ground, litter, grasses and forbs by aspect at Consol's test pit during July, 1972-74.

since initiation of the overall project. Only the use by mule deer has been quantified. The pellet group method was used due to the distinct advantage that pellet groups are an inert kind of evidence which can be subjected to field plot sampling (8). The pellet group counts were made during March, 1974, and data were used to represent use of the area during the previous year. Seasonal use was not distinguished by this method. Seven sites were sampled on topsoil, five on sandstone, three on sandstone-shale, and two on shale.

The average number of pellet groups/acre on topsoil was 436. The maximum number on any one topsoiled site was 980 and a minimum was 0. Sandstone averaged 196 pellet groups/acre with a maximum of 653 and a minimum of 0. No pellet groups were obseved on sandstone-shale or shale sites.

During the spring and fall of 1973, the area was used by mule deer as determined from tracks and direct observation. This use was perhaps related to "greenups" during those respective seasons. Agricultural areas, such as hay meadows and cropland, received similar use (5). During summer of 1973, the abundance of yellow sweetclover on topsoil and sandstone portions perhaps influenced use of these areas by mule deer. This plant was used heavily by mule deer throughout the Bull Mountains during that summer (5). During winter, some utilization of saltbushes was evident and may, at least partly, be attributed to mule deer. The area was fenced to exclude livestock. However, the fences did not entirely fulfill this purpose and some of the year-long utilization of vegetation within the fenced area may be attributed to livestock.

SUMMARY

In summarization, the total vegetational canopy on all substrates increased from 1972 to 1974, but the greatest increase was on topsoil. Crested wheatgrass exhibited the greatest increase in canopy among grasses, while others increased only slightly, remained approximately the same, or decreased. Although the canopy of yellow sweetclover fluctuated considerably between years, it was still the most abundant forb during all three years. As determined from a study in the Missouri River Breaks, there is a direct relationship between the availability of yellow sweetclover, as influenced by precipitation, and its relative use by mule deer (7). Occurrence of shrubs on the site was almost negligible. These conditions reflect three consecutive years of above normal precipitation.

Although the revegetated area may have met some of the forage needs of mule deer during the three years following seeding, it is my opinion that the disturbed area by itself never did provide the diversity of forage necessary to meet year-long forage requirements. The intent expressed in the reclamation plan was to restore the area to grassland for the purpose of grazing. The revegetated test pit did not compare favorably with natural grasslands, either in diversity or relative abundance of plant species, when forage requirements of mule deer in the Bull Mountains are considered (5). For example, the test pit provided an abundant quantity of yellow sweetclover during the summer of 1973, but little else. Shrubs used by

mule deer during winter, primarily silver sagebrush and skunkbush, were virtually nonexistant on the test pit area. Winter is normally considered the most critical time of the year for wildlife.

A home range is defined as an area habitually traveled by an individual animal while engaged in its usual daily activities such as feeding, resting, etc. The average home range of two adult does in the Bull Mountains was 560 acres. For this reason it is difficult to assess the actual impact that disturbance of the 12 acre plot would have on a population of mule deer, or even the deer that occur in the immediate vicinity. However, if the size of the area was magnified, we have a pretty good idea that the result could be detrimental.

CONCLUSION

In conclusion, I would like to make the following recommendation: that less emphasis be placed on revegetating spoils with crested wheatgrass and other exotics, which are obviously easy to establish; and more emphasis should be placed on determining the conditions necessary to re-establish species known to be important to the local ecology.

LITERATURE CITED

1. Booth, W. E. and J. C. Wright. Flora of Montana, Part II--dicotyledons. Montana St. Coll., Bozeman. 305 pp. 1959.

2. Daubenmire, R. F. A Canopy Coverage Method of Vegetational Analysis. N.W. Sci. 33(1):43-64. 1959.

3. Dice, L. R. Natural Communities. Univ. Michigan Press, Ann Arbor. 547 pp. 1952.

4. Dusek, G. L. and S. A. McCann. Bull Mountains Coal Field Study. Montana Dept. of Fish and Game and Consolidation Coal Co. Prog. Rept. 53 pp. 1973.

5. _____. Bull Mountains Coal Field Study. Montana Dept. of Fish and Game and Consolidation Coal Co. Prog. Rept. 76 pp. 1974.

6. Gieseker, L. F. Soils of Musselshell County. Montana Agr. Expt. Sta. Bull. No. 374, Bozeman. 51 pp. 1939.

7. Mackie, R. J. Range Ecology and Relations of Mule Deer, Elk, and Cattle in the Missouri River Breaks. Wildl. Monog. No. 20. 77 pp. 1970.

8. Neff, D. J. The Pellet-group Count Technique for Big Game Trend, Census, and Distribution: a Review. J. Wildl. Manage. 32(3):597-614. 1968.

9. Sindelar, B. W., R. L. Hodder, and M. E. Majerus. Surface Mined Land Reclamation Research in Montana. Montana Agri. Expt. Sta., Bozeman. 122 pp. 1973.

10. U.S. Dept. of Comm. 1972 Climatological Data, Montana. Nat. Ocean. and Atmos. Admin. 75(13):294 and 298. 1972.

11. _____. 1973 Climatological Data, Montana. Nat. Ocean. and Atmos. Admin. 76(13):2 and 5. 1973

12. _____. 1974 Climatological Data, Montana. Nat. Ocean. and Atmos. Admin. 77(13):2 and 5. 1974.

* * *

REHABILITATION RESEARCH AND ITS APPLICATION ON A SURFACE MINED AREA OF EASTERN MONTANA

Bland Z. Richardson, Eugene E. Farmer
Ray W. Brown and P. E. Packer*

Surface mining has reached new heights in the West, and as stripping ratios improve through the use of larger and better equipment, the surface area disturbed increases exponentially.

As surface mined areas are laid bare, deep cuts are made and soil and subsoil materials are transported to adjacent or remote areas where they are blended with other materials and usually turned upside down. This blend is no longer a soil in the agricultural sense, but a mass of heterogeneous, sterile material from which vegetation is expected to grow. Techniques usually used in agricultural soils frequently do not apply here, and new approaches to vegetation rehabilitation must be found. However, it hardly seems necessary to make technical justifications for the proposition that surface mining activities in the western United States are creating many problems, both real and imagined. Federal reports alerted the state and private sectors of the western U.S. to the potentially enormous impacts of mining western coal by surface methods. The extensive coverage that has recently been given to surface mining by newspapers, radio and television has strongly sharpened not only the interest of the general public but also the interest of numerous private environmental groups. The quickened public interest has generated similarly quickened interest in both federal and state legislatures. Almost every western state legislature is considering or has already passed new laws and regulations concerning surface mining. The 94th Congress of the United States is addressing itself to problems of western surface mining.

Recognizing the fact that drastic land disturbance from surface mining was increasing in the West and that many important questions concerning the revegetation of these disturbed areas need to be answered, the Forest Service began surface mine rehabilitation research in the West in 1967 and redirected this research to an expanded effort as the "SEAM" (Surface Environment and Mining) program in March 1972.

Although surface mine and mineral exploration disturbances on western mountain rangelands occur in virtually every vegetation zone of the West, four vegetation zones that are being severely affected are: 1) the upper sagebrush foothills associated with aspen and Douglas-fir, 2) the mountain-coniferous forest zone, 3) the alpine tundra zone, and 4) the Great Plains. Accordingly, in 1972, five surface mines that are representative of the kinds of problems associated with each of these vegetation zones were

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selected for revegetation research. These mines are: 1) the Ballard phosphate mine in southeastern Idaho, 2) the Blackbird copper-cobalt mine in central Idaho, and the Leviathan sulfur-copper mine in the Sierra-Nevada of California, 3) the Stillwater mineral complex on the Beartooth Plateau in southern Montana, and 4) the Decker coal mine in southeastern Montana.

The rehabilitation problems that characterize each of these mines were attacked by employing a 3-stage research, development, and application effort:

Stage 1.--Testing and evaluation of several levels of treatments designed to establish vegetation on mine spoils. We believe that in addition to introduced grass species, both native grasses and shrubs should be investigated to assess the possibility of initiating or speeding-up natural successional processes that result in stable plant communities. In this stage, emphasis was placed on the determination of treatment effects and on the performance of selected plant species. To focus this emphasis, all study sites were level and, consequently, free of the many influences associated with slopes and aspects.

Stage 2.--The second stage of this work was to extend the most favorable results from stage 1 to sloping areas of varying steepness on different aspects. The principal complications that are introduced with slopes are soil erosion, the movement of nutrients and seed, changes in microclimate as influenced by aspect, and the changes in equipment and technique required to physically accomplish the job.

Stage 3.--The last stage was to transpose the accumulated information and techniques developed during stages 1 and 2 to a pilot scale revegetation effort on surface mine overburden piles. In this effort we specify plant species and also correct equipment and techniques. This stage has two purposes; (a) application and demonstration of research results, and (b) field research on the problems associated with operational scale efforts.

The balance of this paper deals with the Decker coal mine and, while it is primarily concerned with the accomplishments of stage 1, it also is a progress report on stages 2 and 3.

Why is the U.S. Forest Service conducting research at the Decker mine in southeastern Montana? For several years three of the authors of this paper have been involved in research on the vegetation and soils of the Fort Union Formation in southeastern Montana. Brown (1,2) studied the ecological distribution of plant communities on the badlands of southeastern Montana, concentrating on native plant community composition and plant succession. Richardson studied the infiltration capacities and erosion potentials of soils in the same area from 1964 to 1969 (data on file, Forestry Sciences Laboratory, Logan, Utah). Both of these scientists participated in the soil and vegetation survey of the Ashland Division of the Custer National Forest during this period. More recently, Packer (5) made a study to evaluate rehabilitation potentials and limitations of surface-mined land in the Northern Great Plains.

When the Decker Coal Co. began operations at Decker in 1971

we felt this would be a logical location to initiate rehabilitation research. Not only was it a new mine, but also we had considerable experience with the soils and geological parent materials of that area. Additionally, earlier work with the vegetation of that region gave us some insight into the native plant species best adapted to severely disturbed sites. The similarities between the exposed parent materials on badland formations and the overburden spoils resulting from mining were striking, and we were able to apply our earlier research on plant succession directly to the rehabilitation problem at Decker. Next, the Decker Coal Co. agreed to furnish study sites, supply equipment for shaping mine spoils, and provide protection to the research sites from grazing and other uses during the research period. Finally, the Forest Service's interest in the environmental impacts of coal mining and in the potentials and limitations for rehabilitation of coal mine spoils in the Northern Great Plains is prompted by the fact that surface-minable coal underlies many thousands of acres of the Custer National Forest and other Federal lands in the Great Plains, including the National Grasslands for which the Forest Service is administratively responsible to the public.

The Decker mine is located near Decker, Montana, just north of Sheridan, Wyoming. Commercial operations started in 1971 in a subbituminous coal seam averaging about 50 feet thick. The coal is buried under approximately 60 feet of overburden. This overburden material is removed from the coal bed with heavy equipment and placed into an adjacent cut from which the coal has been removed (3).

The natural vegetation of the general area reflects the annual precipitation of about 15 inches. It consists primarily of mixed grass prairie and scattered shrubs. The dominant vegetation on the gently rolling slopes is needle-and-thread (*Stipa comata*), green needle-grass (*S. viridula*), western wheatgrass (*Agropyron smithii*), blue grama, (*Bouteloua gracilis*), and big sagebrush (*Artemisia tridentata*). In the swales, salt grass (*Distichlis stricta*), western wheatgrass, and big sagebrush are dominants (2).

Primary Objectives

Primary objectives of the study are:

1. To determine the minimum combination of treatments necessary to achieve an acceptable stand of grass, shrubs, and trees. Treatments refer to fertilization, topsoiling, irrigation, and soil mulching.

2. To assess the short- and long-term merits of grass mixtures consisting of (a) all introducted grasses, (b) all native grasses, and (c) native plus introducted grasses.

Secondary Objectives

Secondary study objectives are:

1. To assess the feasibility of revegetation methods other than seeding, e.g., transplanting and sprigging.

2. To evaluate the influences of various soil cultural practices upon stand establishment. The soil cultural practices include varying methods and degrees of preparation of seedbed, and varying means of firming the seed into the seedbed.

METHODS

Study methods related to primary objectives are:

1. Study site selection: The site selected for study was on level spoil material, chosen to avoid the effects of slope, aspect, and steepness, and to avoid complications associated with seed and plant nutrient movement.

2. Observations of plant species and their distribution:

Low-level infrared false color and color aerial photography was made with accompanying "ground truth" measurements to record plant communities, their vigor, and densities prior to mining.

3. Selection of plant species: Native plant species in the immediate vicinity of the mine are climatically adapted to the area, and may offer the best source of plant material for revegetation. Indigenous species are particularly adapted to not only long-term climatic patterns but also to periodic unusual droughts or other conditions that characterize the area. However, certain introduced species may serve a useful purpose for revegetation, particularly those that demonstrate competitive aggressiveness and an elastic adaptability in certain niches. Some annual and biannual species may prove successful for secondary succession. Also, some introduced perennials occupy niches in the successional scheme that provide a suitable environment for the invasion and ultimate occupation by more stable native species.

Plant distribution patterns on old mining disturbances, on road cuts and fills, on or immediately adjacent to the mine, and on other disturbances in the near vicinity of this mine were carefully studied. Those plant species that have demonstrated adaptability and a longevity of survival on drastically disturbed sites were selected to use in this study. It should be recognized that a single plant, whether it be native or introduced, found successfully growing in a disturbed site is, in itself, a discovery of profound significance. Care was taken to record species, environmental conditions, growth habits, and season of growth and maturation.

4. Seed collections: Seed and other propagation materials (e.g., rhizomes, rootstalks, stem cuttings, etc.) were collected on the mine and surrounding area as they matured or otherwise became available. This required a number of different collecting trips to the Decker mine during the growing season because of the differences in time that various species mature their reproductive parts. Seeds were collected by hand, stored in cloth bags, and labeled with species name, date of collection, exact location, and associated species information. Stem cuttings, and other vegetative parts, were stored in plastic bags, labeled as above, moistened slightly, and sealed to prevent evaporation.

These plant materials were processed as soon as they

were returned to the laboratory. Seeds were air-dried, separated from the other flower and plant parts on the seed board, then cleaned with a seed blower. Clean seed was stored in cloth bags in a dry coldroom at 34°F. Stem cuttings and other vegetative parts were prepared for transfer to the greenhouse or mist bench as required.

It was necessary to purchase seed of some introduced species from commercial sources. Only certified seed with known origin, germination, and inert matter content was accepted. Commercial seed usually originates at locations remote from the surface mine, a fact that will be considered when assessing stand establishment in later years.

5. Site construction: The Decker coal mine research site was constructed near the coal test pit. This location was selected because there was little danger of the research site being disturbed for some years. The site was marked with both cut and fill stakes. Construction equipment was furnished by the Decker Company and operated by it. Any soil and subsoil above spoil materials was removed from the area and replaced with mine overburden material selected by the researchers. The spoil material for building the study site was moved to the area using a 30-yard, land leveling scraper and a D-9 tractor.

6. Collection of soil samples: Composite soil samples were taken from the study site and analyzed for chemical and physical properties as well as nutrient requirements. Soil samples were also taken from every subplot within the irrigated and control plots. A soil survey made by the Decker Company of the mine area was available.

7. Preparation of seed packets: Three different seed mixtures were prepared, each consisting of several species: (1) natives, (2) introduced, and (3) native plus introduced. (See listing, next page.) The seeding rate was 25.5 lbs. per acre for each mixture. This rate was about twice that recommended for most revegetation attempts because of the lack of definitive seeding rate data for sterile surface mine spoils. This seeding rate represents the quantity of live viable seeds only, as determined by prior germination tests in the laboratory.

The mixtures and seeding rates used on the Decker mine are listed in the following tabulation. The quantities of seed used per 8-foot square subplots (64 sq. ft.) are in grams to facilitate weighing in the laboratory during seed packet preparation. The equivalent weights in pounds per acre are also shown. The seed of each species was weighed out to the nearest 0.1 gm. The mixture was thoroughly mixed with a seed-carrier (e.g., rice hulls), sealed in cartons, and labeled prior to transportation to the mine site. The inert seed-carrier was used to increase the volume of each packet to help insure even distribution on the subplots. An individual packet with the proper treatment was prepared for each subplot to be seed.

NATIVE SEED MIXTURE

Species	Grams per subplot	Lbs. per acre
Green needlegrass	3	4.5
Western wheatgrass	4	6.0
Blue grama	2	3.0
Little bluestem	1	1.5
Sideoats grama	2	3.0
Indian ricegrass	1	1.5
Slender wheatgrass	3	4.5
Big bluestem	1	1.5
Total	17	25.5

INTRODUCED SEED MIXTURE

Fairway crested wheatgrass	2	3.0
Nordan crested wheatgrass	2	3.0
Russian wildrye	3	4.5
Pubescent wheatgrass	2	3.0
Intermediate wheatgrass	2	3.0
Smooth brome (Manchar)	2	3.0
Winter rye	2	3.0
Tall wheatgrass	2	3.0
Total	17	25.5

NATIVE + INTRODUCED SEED MIXTURE

Fairway + Nordan crested wheatgrass	3	4.5
Green needlegrass	2	3.0
Smooth brome	2	3.0
Western wheatgrass	3	4.5
Russian wildrye	2	3.0
Blue grama	1	1.5
Intermediate wheatgrass	2	3.0
Slender wheatgrass	2	3.0
Total	17	25.5

8. Preparation of fertilizer packets for the Decker mine: Fertilizer requirements determined from soil analyses indicated that a 15-40-5 ratio of N-P-K was required at an equivalent rate of 45 pounds of N per acre (or 300 pounds bulk per acre) in addition to other nutrients.

A commercial chemical fertilizer was used. Fertilizer packets for each subplot receiving a fertilizer treatment were prepared. Each packet contained the required amount of fertilizer for a 64 sq. ft. subplot and 500 gm of inert washed sand as a carrier. The mixture was labeled in sealed cartons for each

study subplot.

9. Seedbed preparation: Good seedbed preparation is necessary for successful establishment of grass species. Different methods may be used, but it is always essential that the seedbed be firm. Loose seedbeds permit plant roots to grow into air pockets between soil particles. Moisture tension is then broken between the plant and the soil, causing a lethal water potential condition for the plant.

The Decker mine study site was prepared using a grader to thoroughly rip the spoil and top soil to a depth of 10 inches. A harrow cultivator equipped with wheels was then used. The tines of the cultivator were of a Danish type and had a high frequency of vibration insuring better tilth and a more uniform seedbed. After cultivating to a 6-inch depth, the wheels of the cultivator were adjusted to a 2-inch depth. The tines were adjusted to four inches apart. One pass was made with the harrow, after which all surface rocks over two inches in diameter were removed. The area was packed, using a cultipacker. The harrow was then set for a 2-inch depth and cultivated one more time in one direction. The seedbed was then ready to receive the seed.

10. Application of seed and appropriate treatments: Grass seed for the Decker mine was applied with a cyclone seed sower designed and operated to give even distribution of seed throughout the 64 sq. ft. subplots (Fig. 1).

11. Firming seed into seedbed: Seedlings will not emerge if planted too deep. Uncovered seed, however, may not germinate unless ample ground moisture is available. To cover and firm seed into the seedbed, a cultipacker seeder without the seed attachments was used. This machine accomplished the following (Fig. 2):

a. Planted broadcast seed of different masses at varying depths which insured optimum germination of a maximum number of seeds when all seeds had to be planted at the same time.

b. Crushed lumps, pressed down small stones, and formed a firm seedbed with specially designed frontrollers.

c. Split the furrows made by the front rollers and planted seed.

d. Created small depressions in the soil for seed "catches" as well as small pockets to trap water and increase infiltration.

e. Made soil less likely to form an impervious layer which would hinder emergence.

12. Mulching: Mulch was applied by using a single-layer jute netting over a thin layer of sphagnum peatmoss (Fig. 3).

13. Staking and tagging subplots: Each of the subplots within plots was staked and tagged. Each tag contained subplot identification information and treatment data.

14. Appropriate application of water: The irrigated study plot contained a contiguous group of 48 subplot (8- by 8-feet), that was irrigated during the first two growing seasons. Irrigation water was applied with a specially designed sprinkler system which was varied with the climatic modification desired, depth of water application, and the evapotranspiration rate for the area. Water application was greatly reduced the second year to encourage greater root penetration.

15. Monitoring soil water conditions: The soil water status on the study area was monitored periodically during the growing season in an attempt to determine the impact of this frequently limiting factor on plant establishment and growth (Fig. 4).

Data Collection

Two types of data were collected for the 144 subplots: (1) grass stand density, and (2) estimates of the dry weight grass production. During data collection, all measurements and counts were made on the interior 6- by 6-foot area of each subplot. This action separated subplot treatments with a buffer zone 2 feet wide.

Early in the growing season, seedling emergence was assessed by making grassseedling density estimates on the top-dressed plot and on the control plot only. All of the seedlings were counted on a randomly selected 10-square-foot area of each subplot.

Estimates of the dry-weight production of grass on each subplot were made in October 1973 and October 1974. Nondestructive sampling was imperative since future measurements are required. Therefore, the Neal capacitance meter, Model 18-1000, was used to estimate production (4). To calibrate the capacitance meter, one of every six herbage plots (1 by 2 ft.) read with the meter was clipped and the dry weight measured.

1973 Results

During the 1973 growing season, weather conditions were generally favorable for plant growth. From April through September, precipitation amounts were approximately 15 per cent above the long-term mean. Average daily air temperature was slightly below normal. Therefore, for the Decker mine site, the weather during this first growing season can be characterized as cool and moist (3).

Generally the greatest yields during the first growing season came from the mixture of introduced grasses, which averaged 789 pounds per acre, and the smallest yields from the mixture of native grasses, which averaged 629 pounds per acre. However, the native grass mixture performed better than expected in the first growing season with a maximum production of 1,543 pounds per acre. Several of the more favorable treatments yielded native grass stands that would provide good erosion protection to the soil (3).

1974 Results

Preliminary results of the second year of revegetation research on the Decker mine show a general trend toward improved establishment from 1973. Figure 5 summarizes the grass production results for 1974, while Figure 6 compares the grass production results between 1973 and 1974. Generally the greatest yields came from mixtures of native and introduced grasses which averaged 2257 lbs. per acre in 1974. In 1973 the greatest yield came from a mixture of introduced grasses which averaged 789 lbs. per acre. The smallestyields in 1974 came from a mixture of introduced grasses which averaged 1745 lbs. per acre, whereas in 1973 native grasses provided the smallest yields, averaging 629 lbs. per acre.

Grass yield mean may be grouped according to grass mixtures and ranked by treatments (Fig. 7).

DISCUSSION

Following is a summary of highlights from the 1973 and 1974 revegetation results from Forest Service research plots at the Decker coal mine. The 1973 results are summarized in the paper entitled "Revegetation Research on the Decker coal mine in southeastern Montana" (3). Grass production from the various treatments during 1973 and 1974 is summarized in Table 1. Grass production on the Decker mine research area was substantially better in 1974 than in 1973. Almost without exception, wheat-grasses (Agropyron species) are the dominant plants. Except during the most severe drought conditions, wheatgrass plants usually do better in their second year of growth than in the first year, but may fall off some in the third year.

Most of the conclusions drawn from the 1973 Decker data were substantiated or strengthened by the data in 1974. For instance, 1973 results showed all of the subplots located on the top-dressed soil yielded acceptable stands. In 1974 this statement is even more true; production on this main plot tripled (see Table 1). First-year results indicate several treatments yielded grass stands capable of adequately protecting the spoil material against either water or wind erosion. This statement has been verified and strengthened by a comparison of 1973 and 1974 results. Average grass yield on unirrigated fertilized raw spoils increased from 391 lbs. per acre in 1973 to 2065 lbs. per acre in 1974. The average grass production on the irrigated fertilized raw spoils increased from 1323 lbs. per acre in 1973 to 3738 lbs. per acre in 1974. The unfertilized top-dressed subplots increased in grass production from 813 lbs. per acre in 1973 to 2146 lbs. per acre in 1974. Compare these yields to the average yield of 884 lbs. per acre on native range prior to mining disturbance (1). Clearly, at the end of the second year of research at Decker grass production on top-dressed, irrigated, and even on unirrigated raw spoils was substantially greater than that on undisturbed native range. In 1973, the introduced pasture grasses clearly outproduced the other two seed mixtures. However, this condition has changed during the 1974 growing season, and all three grass mixtures are now producing at approximately the same level. This is strong evidence that native grasses will respond

favorably to rehabilitation inputs at Decker.

The purpose of an irrigation plot was to show the effects of optimum water on plant germination and establishment. The test pit water was used for irrigation in 1973 and 1974 because it was available and the high sodium content could be evaluated for establishing grass stands in the event this water source had to be utilized during the occasional drought years that occur on the Northern Great Plains. While this pit water is certainly not the best, it is the most convenient and most readily available water source at Decker. Results of our research indicate that the pit water can be used to establish grass stands provided the necessary measures are taken to counteract the adverse effects of sodium. This was done in 1973 with an application of calcium chloride, but did not have to be repeated in 1974. We have never thought of, nor advocated, the use of irrigation as a standard long-term operating procedure. Last year was the second and last season of irrigation on our research site at Decker (Fig. 8).

Stage 2 of this study began with the installation of research plots on a 1 to 5 slope just above the test pit. Six plots were installed as a fall planting in 1973 and the plantings were duplicated in the spring of 1974. The spoil material is similar to that used on the 1972 study plots. The first results of this study will be published in the spring of 1976; however, preliminary results indicate that the fall planting is far superior to the spring planting and that mulching increases not only emergence but significantly increases root and shoot production the first growing season.

Stage 3 of this study began in the fall of 1974. The best information and techniques developed during stages 1 and 2 were applied to an 8.6-acre pilot demonstration area (Fig. 9). First results from this area will be gathered in spring 1975 when emergence is evaluated. Other treatments to be evaluated are: grass seed mixtures, mulches, fertilizers, sewage sludge, planting methods and depth of top soiling.

Other studies in progress and related to the Decker mine are (1) Hydromulching as an alternative revegetation method on surface mine disturbance; (2) the water relations of shrubs and trees used for surface mine rehabilitation; (3) use of organic soil amendments in the revegetation of surface mines; (4) hydraulic planting and mulching as a revegetation method on steep overburden piles; (5) the comparative value of selected inorganic fertilizer; (6) performance of individual grass species on overburden materials; (7) aerial remote sensing of microenvironments for surface mine reclamation; (8) a reconnaissance survey of spoil types and their hydrologic responses, and (9) leaching as a treatment to improve the physical and chemical characteristics of the soil.

Table 1.--Grass production on Decker revegetation research plots

Treatments	Dry wt. lbs./acre	
	1973	1974
Control plot (RAW SPOILS)		
Highest yielding treatment	881	3086
Lowest yielding treatment	66	206
Average yield (fertilized)	391	2065
Average yield (unfertilized)	282	319
Irrigated plot (RAW SPOILS)		
Highest yielding treatment	2238	4902
Lowest yielding treatment	352	301
Average yield (fertilized)	1323	3738
Average yield (unfertilized)	439	428
Topdressed plot (ON-SITE TOPSOIL SPREAD OVER RAW SPOILS)		
Highest yielding treatment	1309	4457
Lowest yielding treatment	502	1558
Average yield (fertilized)	1012	3905
Average yield (unfertilized)	813	2146
Native range (undisturbed) unfertilized average		884

Figure 1.--Enclosures confined individual treatments to subplots.

Figure 2.--Aculti-packer seeder was used to firm seed into seedbed.

Figure 3.--Single layers of jute netting were applied for the mulch treatment.

Figure 4.--Lack of water reduced survival of many plants on the control plot.

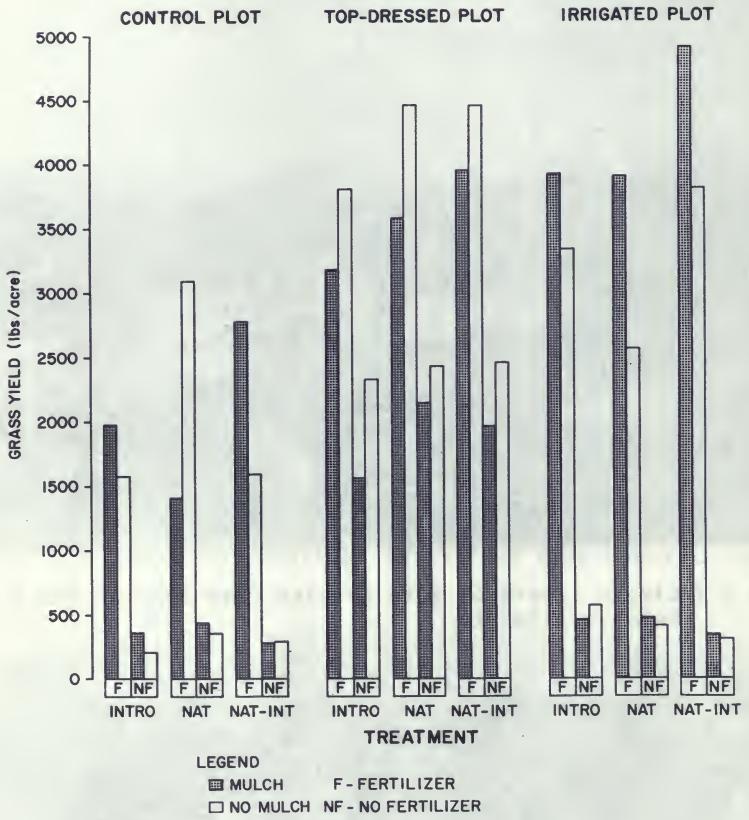


Figure 5.--Average 1974 dry-weight grass production, for each main plot by subplot treatments. Intro (introduced), Nat (native), and Nat-Int (Native-Introduced) are seed mixtures.

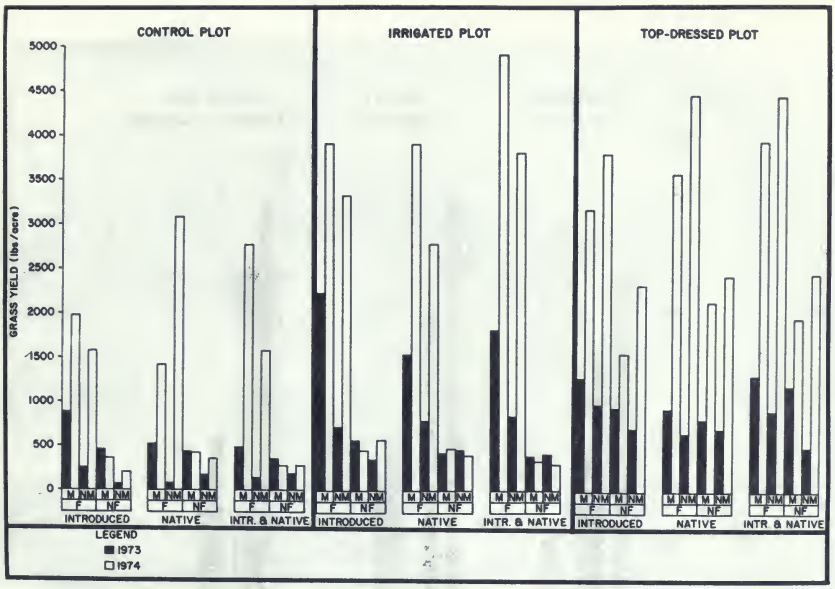


Figure 6.--Comparison between average dry-weight grass production for each main plot by subplot treatments for years 1973 and 1974.

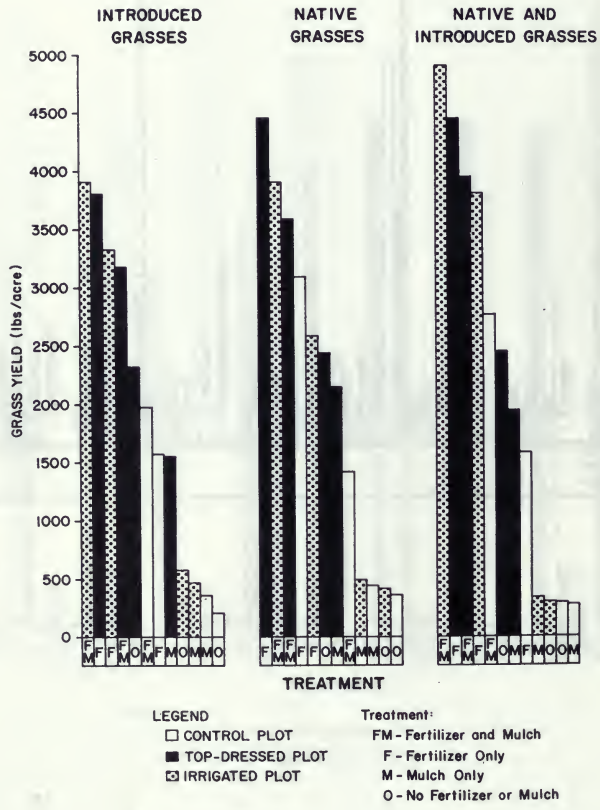
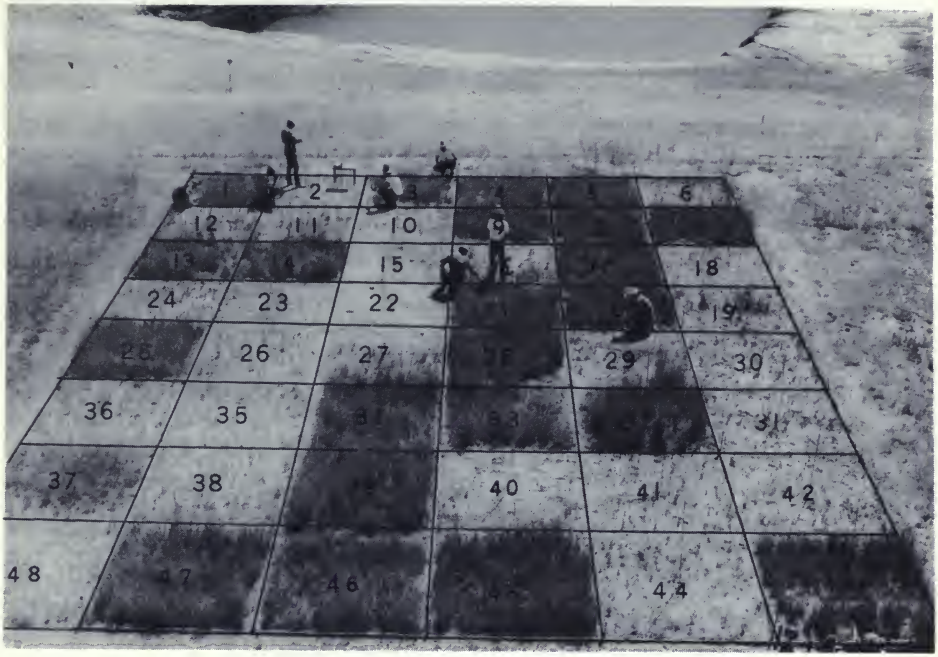


Figure 7.--The average dry-weight grass production by treatments, ranked within grass mixtures.



Grass mixture	Fertilizer treatment	Mulch treatment	Subplot numbers	Dry-weight av.lbs./ac. 1973	1974
Native	yes	yes	13-37-39-47	1543	3903
Introduced	yes	yes	17-33-32-45	2238	3917
Nat. + Int.	yes	yes	9-14-21-25	1813	4902
Native	yes	no	3-5-22-20	784	2570
Introduced	yes	no	4-7-28-43	722	3332
Nat. + Int.	yes	no	1-8-34-46	840	3802
Native	no	yes	6-12-24-38	425	485
Introduced	no	yes	11-16-27-31	576	461
Nat. + Int.	no	yes	30-40-41-42	392	338
Native	no	no	10-29-36-44	467	408
Introduced	no	no	15-19-26-48	352	576
Nat. + Int.	no	no	2-18-23-35	422	301

Figure 8.--Irrigated plot layout with treatments.

Figure 9.--Treatments used on the demonstration area in the foreground were from accumulated information and techniques developed during stages 1 and 2 (1972-1973).

LITERATURE CITED

1. Brown, R. W. The distribution of plant communities in the badlands of southeastern Montana. M.S. Thesis, Univ. of Montana. 145 p. 1965.

2. Brown, R. W. Distribution of plant communities in southeastern Montana badlands. Am. Midl. Nat. 85:458-477. 1971.

3. Farmer, E. E., R. W. Brown, B. Z. Richardson, and P. E. Packer. Revegetation research on the Decker coal mine in southeastern Montana. USDA For. Serv. Res. Pap. INT-162. Intermountain Forest and Range Experiment Station, Ogden, Utah. 1974.

4. Neal, D. L., and J. L. Neal. Uses and capabilities of electronic capacitance instruments for estimating standing herbage. J. Br. Grassland Soc. 28:81-89. 1973.

5. Packer, P. E. Rehabilitation potentials and limitations of surface mined land in the Northern Great Plains. USDA For. Serv. Gen. Tech. Report INT-14. Intermountain Forest and Range Experiment Station, Ogden, Utah. 1974.

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SHORT AND LONG TERM FERTILIZER REQUIREMENTS FOR RECLAMATION OF MINE SPOILS AT COLSTRIP, MONTANA

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Erick Sundberg

INTRODUCTION

This paper describes research at Western Energy's Rosebud Mine to determine short and long-term fertilizer requirements of mine spoils plantings. Included is a discussion of how we believe our present fertilizer research activities will result in development of an operational fertilizer program for reclamation at Colstrip. We intend to present our research program at the Western Energy Company as a case history for examination by others in similar research programs.

We ask that our research approach rather than specific fertilizer applications be given consideration for merit at other mine locations. Nutrient needs of vegetation on spoils are likely to vary considerably from mine to mine. The methodology developed to determine these needs, however, is likekly to be standard enough to be applicable at many locations.

THE STUDY AREA

The research reported herein was conducted at Pit No. 6 of the Rosebud Mine just south of Colstrip, Montana. Colstrip is situated roughly 30 miles (48 km) south of Forsyth at an elevation of 3220 feet (981 meters). A brief discussion of the geology, soils, climate, and vegetation of the study area follows.

Geology

Geologic formations of the Colstrip area are Upper Cretaceous and Tertiary in age with the exception of some terrace gravel of the Pleistocene age and recent alluvium. Of importance for surface mining is the Fort Union Formation which consists of light-colored sandstone, sandy shale, carbonaceous shale and lignite beds. In geologic times much of the coal along the outcrops burned. The resultant heating of surface materials formed a resistant porcellanite or "scoria." These extensive areas of scoria along with the more easily weathered sandstones of the Fort Union Formation have had a dominant influence on the general topography which has developed (12).

Soils

Soils of the Colstrip region are poorly developed but similar to many other soils developed in a semiarid climate. The soil association in the immediate study area is a fine loamy and loamy skeletal lithic Haploboroll (7th approximation) (6). It is rated as having fair productivity and poor stability (6).

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Soils of the study area have also been described as azonal in nature and including lithosols, regosols and alluvial soil groups (6, 12).

Climate

A continental climate, cold in winter and warm in summer, is found at Colstrip. Average annual temperature extremes are 15° F (-10° C) to 90° F (30° C). Average annual precipitation is 15 inches (38 cm). Almost 50 percent of this occurs as rain in the months April through July (11). Precipitation during the rest of the year is fairly well distributed although actual amounts of winter precipitation likely vary because of blowing and drifting snow. A growing season of about 120 days duration can be expected at Colstrip.

Vegetation

Vegetation of the Colstrip area (Figure 1) consists of mixed prairie-grasslands-pine woodlands type (11). Grasses on native range are predominantly cool season bunch grasses, although a number of warm season grasses can be found. The most commonly found species include bluebunch wheatgrass (*Agropyron spicatum*), western wheatgrass (*Agropyron smithii*), thickspike wheatgrass (*Agropyron dasystachyum*), needle-and-thread (*Stipa comata*), little bluestem (*Schizachyrium scoparium*), green needlegrass (*Stipa viridula*), blue grama (*Bouteloua gracilis*), and prairie junegrass (*Koeleria cristata*). Silver sagebrush (*Artemisia cana*), three-leaf sumac (*Rhus trilobata*), and big sagebrush (*Artemisia tridentata*) are dominant shrubs. Lesser shrubs include yucca (*Yucca glauca*), snowberry (*Symphoricarpos spp.*) and rubber rabbitbrush (*Chrysothamnus nauseosus*). Other grass-like or shrub-like plants commonly found include fringed sagewort (*Artemisia frigida*), sedges (*Carex spp.*), and broom snakeweed (*Gutierrezia sarothrae*).

EARLY FERTILIZER APPLICATIONS

The need for application of fertilizer amendments was recognized from the time of the earliest reclamation trials at Colstrip. Examination of mine spoils of 20 to 30 years age showed that vegetative growth, even in the most favorable sites, often lacked vigor and denseness when compared to undisturbed sites (Hodder, personal communication, 1974).

In a 1970 reclamation trial at the Rosebud Mine (3), thickspike wheatgrass was broadcast onto a prepared soil surface and fertilizer was applied at 50, 100, 150, and 200 pounds per acre each of total N, available P_2O_5, and water soluble K_2O, hereafter referred to as N, P_2O_5, and K_2O. Fertilizer applications had no statistically significant effect on seedling densities which were first observed. Substantial densities (41 plants per ft^2) occurred with no fertilizer. The authors reported, however, that the effect of fertilizer was more clearly indicated by an increase in aerial cover of all species.

In another early fertilizer trial (3) nitrogen, phosphorus, and potassium were applied in a soils media study at 75, 150, and 62 pounds per acre of N, P_2O_5, and K_2O respectively. From this

Figure 1. Vegetation in the Colstrip area is a mixed prairie-grasslands-pine woodlands type. Ponderosa pine (*Pinus ponderosa*) in the foreground is the dominant species.

study phosphorus and potassium were concluded to be low but correctable with additions of the same nutrients in fertilizer form.

A field study designed specifically to evaluate the effectiveness of varied rates of fertilizer was performed in 1972 at Colstrip (10). Winter wheat was planted and fertilized in factorial combinations of three nitrogen levels (0, 75, and 100 pounds per acre) and of four phosphorus levels (0, 50, 100, and 150 pounds per acre). No potassium was applied in this study as levels of this element were considered to be adequate. Plant production expressed as dry weight per unit area generally increased with increasing amounts of fertilizer. The highest rate of application, 100 pounds N per acre and 150 pounds P_2O_5 per acre, did not produce significantly more plant material than 75 or 100 pounds N and 50 pounds P_2O_5 per acre. As a result of this study 50 pounds or greater P_2O_5 per acre on new mine spoils has been considered sufficient to meet first year plant requirements. Since then, increased emphasis has been placed on effectiveness of varied nitrogen applications.

ON-GOING FERTILIZER STUDIES

The first fertilizer experiments at Colstrip obviously contributed much needed information on the response of freshly graded mine spoils to fertilization, but they did not supply sufficient data to prescribe an operational (large scale) fertilizer program. Answers were and are much needed to such questions as: (1) what are long-term fertilizer requirements of mine spoils vegetation?, (2) how do fertilizer requirements differ between native and introduced plant species?, (3) how does fertilizer application affect root production and distribution?, (4) will fertilizer applications affect the palatability and nutrient content of the vegetation if later grazed by livestock? and (5) what are alternatives to applications of chemical fertilizers? The following discussion outlines new research studies at Colstrip and the objectives that they will achieve:

SEAM Study (Surface Environment and Mining)

A long-term project founded by the U.S. Forest Service SEAM program was initiated in June of 1974 which these objectives: (1) to determine the rate of establishment, productivity, and long-term survival of a perennial seed mixture as effected by fertilizer application, (2) to determine the effectiveness of these fertilizer applications in a spring and fall planting, and (3) to determine the optimum duration of annual maintenance fertilization. Intensive soil sampling to determine fertilizer utilization under different fertilizer programs is underway.

Soil improvement studies

The use of green manure crops as an alternative to chemical fertilizers in improving soil fertility and organic matter levels will be investigated. In addition to proven legume species, highly productive weeds such as Russian thistle (*Salsola kali*) and summer cypress (*Kochia spp.*) will be tested for their soil improvement abilities. This idea may not be as farfetched as it first appears since these noxious weeds are extremely well adapted to disturbed sites..

Old Reclamation Plantings

Well established reclamation plantings, such as in Figure 2, may provide a wealth of information concerning the effects of repeated fertilizer applications or lack of same. Sites such as these are being intensively sampled to determine soil fertility status. In addition some of these plantings will be subjected to livestock grazing to determine the effects on nutrient cycling, as well as on plant productivity and community relationships.

DEVELOPMENT OF AN OPERATIONAL FERTILIZER PROGRAM

Now that we have presented a summary of the fertilizer research work that has been conducted at Colstrip and is presently underway, we would like to present means by which an operational fertilizer prescription can be developed taking into account established crop land principles as well as the uniqueness of coal mine spoils. This approach is the basis for fertilizer research being conducted at Colstrip, and it should have merit in research or operational programs at other locations as well.

Overburden Analyses

The first step in determination of fertilizer needs in reclamation should begin with examination of overburden cores before mining. This point has been well covered in many discussions on reclamation (3, 10, 11, 12). In Montana sampling of overburden is a necessary requirement for meeting mining regulations. Aside from determining the general suitability of overburden material for plant growth, we believe that levels of exchangeable ammonium (NH_4^+), nitrate (NO_3^-), phosphorus (P) and potassium (K) should be closely studied. Paleocene shales found in the Fort Union Formation in North Dakota (8) contain large quantities of exchangeable NH_4^+ which, when exposed to the atmosphere by mining, may be transformed to NO_3^- in concentrations adequate to meet requirements of most plants. Power, et al. (9) flatly state that in North Dakota spoils are notoriously deficient in phosphorus but not in nitrogen. In the same paper NO_3^- levels in spoil material ranged from 20-40 ppm (or 80-100 pounds per acre foot) meaning that such soils, other factors being equal, would compete with the most fertile agricultural soils. The implication of Power's (8) work to Montana mine spoils is not certain at this time although at Colstrip we occasionally find spoil samples with NO_3-N levels of 10 ppm (40 pounds per acre foot) or greater.

Short-term Prescriptions

Amounts of fertilizer to be applied with new reclamation plantings to insure good growth and establishment need to be known. In absence of all other test data we believe that examination of overburden samples should give an indication of these short-term fertilizer requirements. More definite recommendations, however, can be made when fertility of actual spoil material is known and plant/fertilizer correlations can be made.

At Western Energy's Rosebud Mine we find levels of macronutrients in spoils as indicated by Figure 3. When compared to known agricultural soil requirements these nutrient levels are low to extremely low for nitrate-nitrogen and phosporus and

Figure 2. Well established reclamation plantings provide a medium for study of long-term fertilizer requirements and nutrient cycling processes.

adequate to low for potassium. With such levels, significant plant response, particularly agricultural crops, can be expected with applications of nitrogen and phosphorus, providing other soil factors are not detrimental to plant growth (Table 1).

Table 1. Some additional properties of spoil material from pit No. 6, Western Energy Company, that have bearing on soil productivity (unpublished data on file).

Depth increment (feet)	Salt (mmhos)	Na (meq/100g)	pH	O.M. (%)	C.E.C. (meg/100g)[1]
0-1	0.3	0.13	8.8	0.15	28
1-2	0.8	0.13	8.4	0.15	33
2-3	0.8	0.13	8.2	0.15	32
3-4	0.8	0.13	8.2	0.15	28

[1]Highly variable among samples

A step beyond looking at basic soil properties to predict fertilizer needs involves testing of single or mixtures of plant species in the field (Figure 4). Fertilizer trials in conjunction with surface amendments such as surface manipulation (10, 11, 12), irrigation (2), or mulching (2) will be useful in determining the short-term nutrient needs necessary for producing an acceptable vegetative cover.

Above ground forage production may be a good indicator of the effectiveness of fertilizer applications for a variety of vegetative types, depending upon the reclamation objective in mind. Considerable variation in response should be expected as precipitation, temperature and ground surface variation are unavoidable (Figure 5) (1, 5). However, above ground forage production may not be the best index of plant response to fertilizer applications, although it is certainly the easiest to sample. While good top growth may be observed, root development may not occur at the same accelerated level. We are investigating the possibility that NO_3-N from heavy surface fertilizer applications is not being leached deep into the soil with the result that root development is being restricted to the shallow depths. Power et al. (7) found that in absence of heavy rainfall, NO_3-N is not leached below the root zone of a bromegrass stand to any appreciable degree. We are taking a closer look at this problem at Colstrip since root-fastness of many stands appears to be less than satisfactory. Evaluation of the effect of fertilizer N on root development of mine spoils vegetation needs more research emphasis.

There is convincing evidence from the literature (2) and from work at Colstrip (3, 5, 11) that fertilizer applications

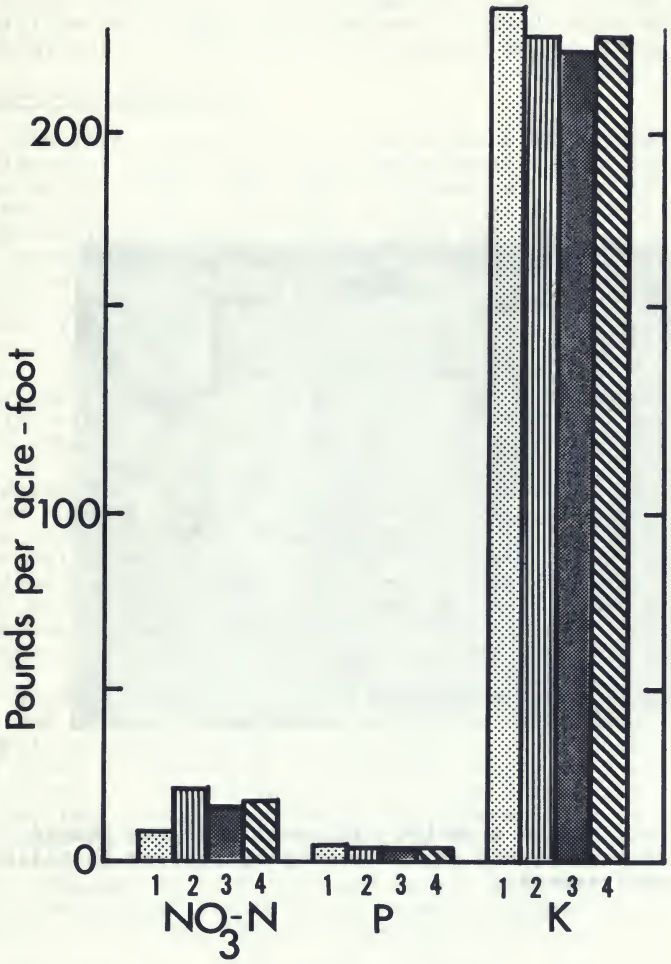

Figure 3. Typical background levels of nitrate nitrogen, phosphorus and potassium by one-foot intervals at pit #6, Western Energy Company, Colstrip, Montana. (Unpublished data on file).

Figure 4. Field trials together with soil analyses should provide a basis for determing short-term fertilizer requirements.

will have no effect on the density and unpredictable effect on first year plant production of perennial grasses. Applications of roughly 50 pounds of N and 50 pounds of P_2O_5 per acre seem to be sufficient at Colstrip for a first year application on raw spoils. Cereal grains when planted in well prepared seedbeds and grown during years of good moisture supply have the capability to utilize much larger applications of fertilizer while perennial plant mixtures respond to a much lesser degree (Figure 5).

Long-term Prescriptions

The rate and duration of maintenance fertilizer applications, necessary to reclaiming spoils to rangeland, has not been determined at Colstrip. The term "maintenance", used often in agricultural fertilizer programs, is probably a misnomer here since we do not really expect that a given nutrient level of mine spoils will need to be continually maintained by application of chemical fertilizers. Rather, we expect that after a period of time (perhaps 3 to 5 years) the nutrient cycling process of spoils vegetation will be sufficient to maintain vigor and productivity comparable to native or "undisturbed" vegetation in a similar climate. To determine the amount and duration of maintenance fertilizer applications, we must periodically assess established mine spoils vegetation (Figure 2) for nutrient status and make frequent comparisons with vegetation from undisturbed areas (Figure 6). Of course, this line of reasoning is only valid if the goal of reclamation is to return the mined land to a semblance of its native species composition and productivity. If mine spoils are to be converted to an alternative land use, study of the original plant-soil complex is not valid. In the case of conversion to cropland, soil nutrient levels would have to be comparable to local agricultural fields in order for farming on mine spoils to be economically attractive. The costs of fertilizer to maintain an equivalent productivity would also be a factor to consider.

We also expect that several alternative long-term fertilizer programs can be developed for meeting a particular reclamation objective. The incremental response to additional applications of a given fertilizer or to different forms of fertilizer may have a bearing on the specifics of fertilizer applications after a vegetative stand is established. Research evidence already indicates that all types of fertilizer N will be adequate in improving grass yields (4, 7). This may not be true for diverse plant communities such as those we are establishing at Colstrip. Also, the possibility of using natural organic or coal derivative organic fertilizers has not been tested sufficiently.

The SEAM study at Colstrip, which we previously discussed, will indicate the returns that can be expected with several long-term fertilizer schemes. By returns, we mean increased protection of the land from erosion, shortening of the time before grazing can be permitted, hastened soil development, and possibly control over species composition of permanently established species. Data from this study, together with our current large scale reclamation plantings, should yield some cost versus return figures which will be extremely valuable in the years to come.

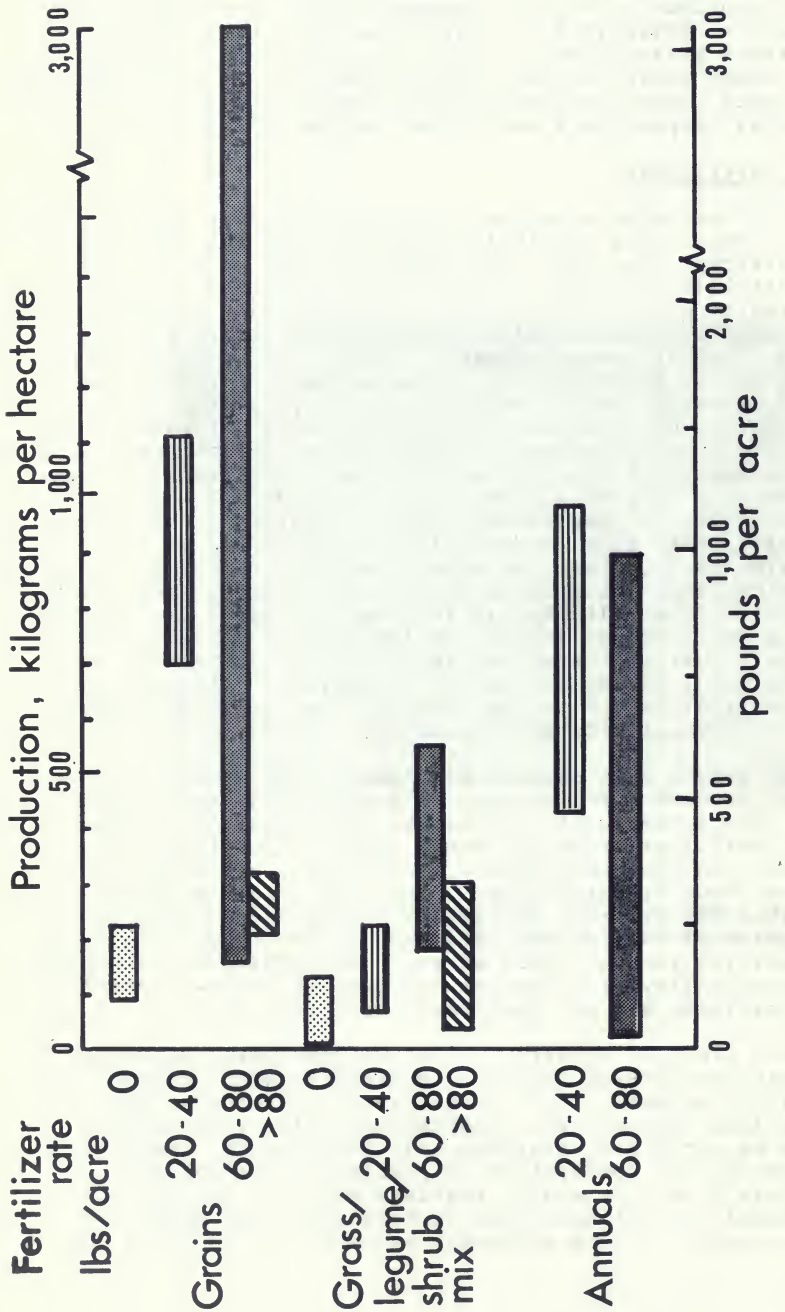

Figure 5. First year forage production (dry weight) of cereal grains, perennial grass-legume-shrub mixtures, annuals planted on mine spoils at Western Energy's pit No. 6 in relation to nitrogen fertilizer level (after Meyn, et al. (5)).

Figure 6. Study of native plant-soil systems should provide a baseline for evaluating mine spoils reclamation in which the goal is to return such land to its original productivity.

CONCLUSION

We believe that with use of established soil analyses techniques, with concentrated research effort, and with recognition of the differences between mine spoils and native soils, an objective and successful fertilizer prescription can be developed for large scale reclamation operations. We have outlined past and present work of our research staff at Colstrip and suggest that a similar approach would be useful at other sites within the Fort Union Formation.

LITERATURE CITED

1. Cooper, C. S. Influence of Harvest Management and Midseason Nitrogen Fertilization on Yield, Botanical Composition and Crude Protein Content of Grass-legume Mixtures. Montana Agricultural Experiment Station Bulletin 676, 15 p. 1975.

2. Farmer, E. E., Brown, R. W. Richardson, B. Z., and P. E. Packer. Revegetation Research on the Decker Coal Mine in Southeastern Montana. U.S. Forest Service, Intermountain Forest and Range Experiment Station, Research Paper INT-162, 12 p. 1974.

3. Hodder, R. L., Ryerson, D. E. Mogen, R., and J. Buchholz. Coal Mine Spoils Reclamation Research Project: Located at Western Energy Company, Colstrip, Montana. Montana Agricultural Experiment Station Research Report 8, 56 p. 1970.

4. Houlton, H. A. A Six Year Study of Vegetative Response to Nitrogen Fertilization on Range in North Central Montana. Montana Agricultural Experiment Station, in press. 1975.

5. Meyn, R. L., Sundberg, E., and R. Young. Research on Reclamation of Surface Mined Lands at Colstrip, Montana. Montana Agricultural Experiment Station, in preparation. 1975.

6. Packer, P. E. Rehabilitation Potentials and Limitations of Surface-mined Land in the Northern Great Plains. U.S. Forest Service, Intermountain Forest and Range Experiment Station, General Technical Report INT-14, 44 p. 1974.

7. Power, J. F., Alessi, J., Reichman, G. A., and D. L. Grunes. Recovery, Residual Effects, and Fate of Nitrogen Fertilizer Sources in a Semiarid Region. Agronomy Journal 65: 765-768. 1973.

8. Power, J. F., Bond, J. J., Sandoval, F. M., and W. L. Willis. Nitrification in Paleocene Shale. Science 183:1077-1078. 1974.

9. Power, J. F., Willis, W. O., Sandoval, F. M., and J. J. Bond. Can Productivity of Mined Land Be Restored in North Dakota? North Dakota Agricultural Experiment Station. Farm Research 31 (6): 30-32. 1974.

10. Sindelar, B. W., Hodder, R. L., and M. E. Majerus. Surface Mined Land Reclamation Research in Montana. Montana Agricultural Experiment Station Research Report 40, 122 p. 1973.

11. Sindelar, B. W., Atkinson, R., Majerus, M., and K. Proctor. Surface Mined Land Reclamation Research at Colstrip, Montana. Montana State University Agricultural Experiment Station Research Report 69, 98 p. 1974.

12. Westinghouse Electric Corporation (Environmental Systems) Colstrip Generation and Transmission Project: Applicants' Environmental Analysis. 1973.

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TREND SURFACE ANALYSIS OF POWDER RIVER BASIN, WYOMING - MONTANA

Teruo Yamamoto*

INTRODUCTION

A premining quantitative evaluation of topographic features in the active and anticipated coal mining areas of the Powder River Basin in Wyoming and Montana is needed which will provide some insights into such basic questions as:

1. How closely should the topography be returned to the way it was before mining?

2. What kind of landscape design is needed so that the mine spoil areas can esthetically blend into the undisturbed landscape?

3. What patterns of surface drainage are applicable to the disturbed area?

4. What can we anticipate, in terms of changes in surface and subsurface hydrology, between disturbed and undisturbed lands?

It should be emphasized at the outset that premining evaluation of the landform elements cannot be expected to provide all the answers to the above questions. However, the initial key to the problem in a geomorphic and hydrologic sense is to detect and understand subtle as well as more obvious topographic distinctions, variations, and their trends on a regional basis by quantitative data rather than by qualitative assessments. Unless the regional geomorphic trends and their ecologic implications are understood, the mere backfilling and recontouring of mined disturbed lands, particularly in areas where major volumetric landscape alteration is expected, are mere cosmetic routines that lack scientific rationale.

Trend surface analysis, by its graphic display, provides a convenient means of understanding spatially variable information.

TREND SURFACE ANALYSIS OF MAPS

Trend surface analysis commonly means least-squares fitting of linear model polynomial surfaces to map data. Trend is therefore defined as a polynomial that may contain all or parts of the linear, quadratic, and higher terms, although in practice the trend rarely exceeds the fifth or sixth degree(3).

The most frequently used geometric relations of the first-, second-, and third-degree equations for three variables are shown

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in Figure 1. The polynomials are described in terms of Z = f (x, y). Each observation of a given dependent variable (Z) at a number of points (x, y) is approximated by a least squares polynomial surface. Every point on the "surface" is defined by two geographic coordinates, x and y, and a magnitude Z (Fig. 1). The simplest surfaces, the first degree, are planes that contain linear terms only; second-degree surfaces contain both linear and quadratic terms and are saddle or bowl-shaped. Third-degree surfaces are oscillatory or doubly sinusoidal in space, and contain linear, quadratic, and cubic terms.

In geology, trend commonly refers to any systematic changes noted on contour type maps, such as structural trends or the "grain" of the map which, for example, shows a north-south alinement. Thus trend surface analysis with its graphic isopleths can objectively represent general trends (or regional effects) of topographic data by a plane of best fit.

The study area approximately covers the central and eastern parts of the Powder River Basin (Fig. 2). Measurements are made, in the main, on 7-1/2 minute quadrangle maps.

Average groundslope (8) is one of the topographic parameters selected to express regional trend because: 1) it can stand on its own as an actual unit of ground surface, 2) all landforms consist of an assemblage of slope elements, and 3) through varying degrees of inclination, landforms directly influence hydrologic and soil-forming processes. Furthermore, average groundslope isopleths are useful in interpreting maps of topographic, isohyetal, soil survey, and geohydrologic nature.

General computer programs tailored to geological data are available (1), (5), (6), (7), (9). The program provided by O'Leary and others (6) with modification is being used for this study. In addition to the contoured trend surfaces, the output includes the equations of each surface of best fit, and several customary statistical-error measures. The latter include the total variance, the variance not explained by the surface, the coefficient of determination, and the standard deviation of the data for each surface of a given degree.

INTERPRETATION OF TREND SURFACE ANALYSIS

The basic idea of this study is to provide baseline standards in deriving topographic norms applicable to strip mining or post-mining treatment (restoring, reclaiming, or rehabilitating disturbed lands) by interpreting the trend surface maps. Disturbed lands are usually restored for cosmetic effect. Sites that are graded to near zero gradients are planted with forest-type vegetation that is expected to eventually smooth out mining impacts with the surrounding landscape. But variations in topographic variables must be interpreted on a regional (as well as on a local) scale, because disruptions from surface stripping are bound to affect not only the visual esthetics but associated land resources of neighboring areas.

Trend contours shown as isopleth maps may be read like a topographic contour map. To illustrate a sample interpretation adapted from Lustig (4), assume that the isopleths in Figures 3

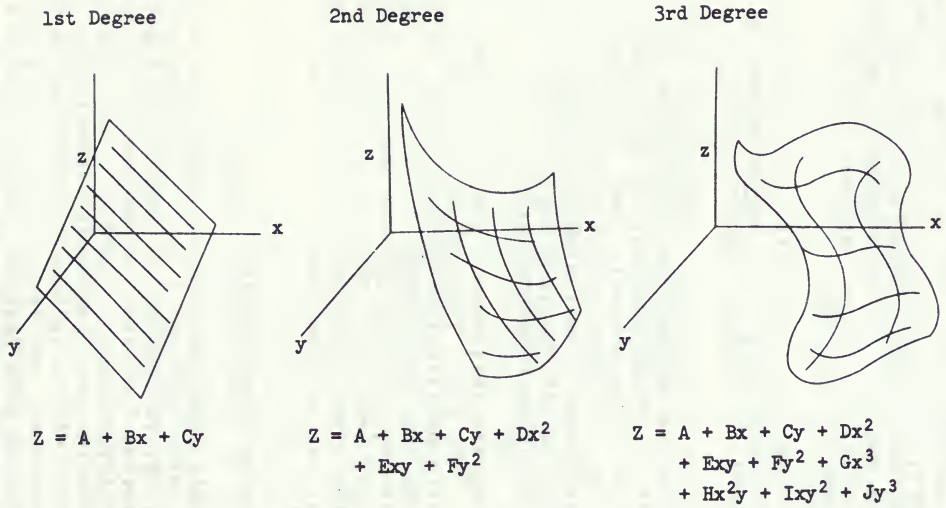


Figure 1. Geometric relations of first-, second-, and third-degree equations for three variables. (Adapted from Lustig (4).)

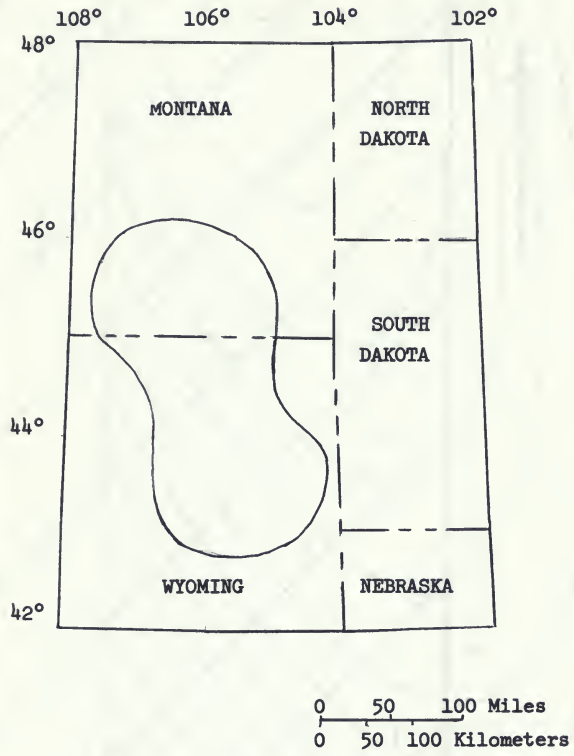


Figure 2. Outline of Powder River Basin in Wyoming and Montana. (Adapted from Keefer and Schmidt (2).)

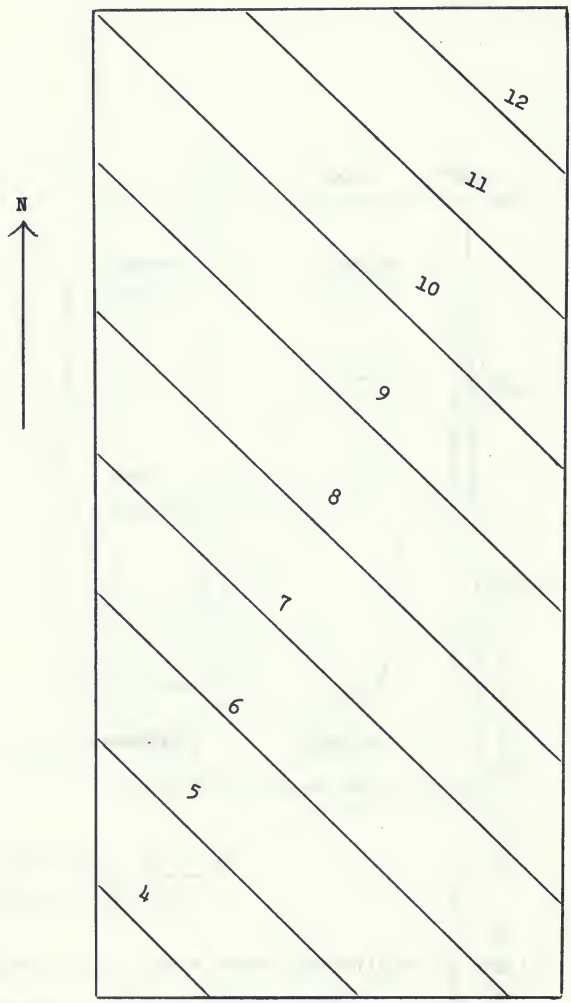
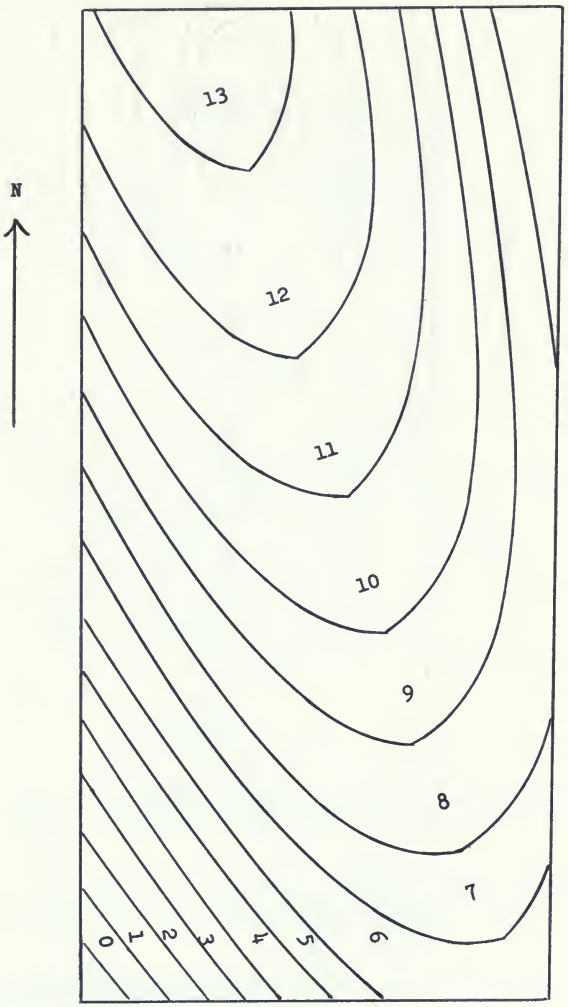


Figure 3. Example of first-degree trend-surface map of average groundslope. Contour interval is one percent. (Adapted from Lustig (4)).



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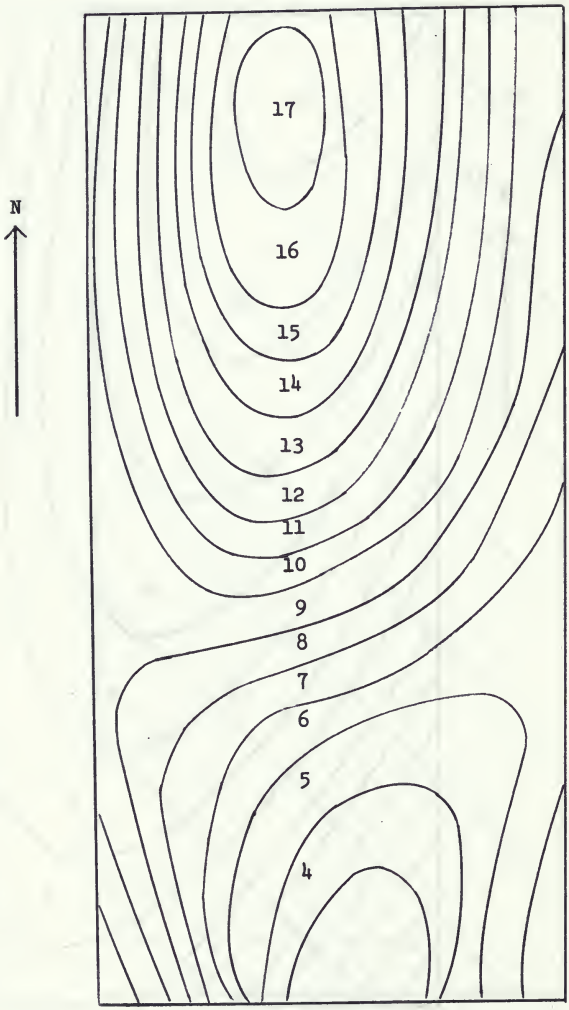

Figure 5. Example of third-degree trend-surface map of average groundslope. Contour interval is one percent. (Adapted from Lustig (4).)

to 5 represent values of groundslope. The slope values of the first-degree map (Fig. 3) decrease (i.e., dip) from northeast to southwest, with a northwest to southeast contour strike. The values range from 4 percent in the southwest to 12 percent in the extreme northeast corner of the map. Therefore, the regional variation is approximately 300 percent for this parameter. Perhaps the simplest kind of spoils replacement that can be formulated from this kind of trend may be to align the overburden spoils with the trend strike so that mean surface flow, for example, is directed generally from the northwest to the southwest. Restoration of relief can then be guided by the contour values. The first-degree fit explains only 25 percent of the total variance, however. This means that the Z values are not uniformly distributed, for example, along a given parallel of latitude.

In contrast to the first-degree fit, the parabolic second-degree fit (Fig. 4) with an explained variance of 32 percent reveals a regional high to the north and west and shows a more rapid decrease of values to the southwest than to the southeast. Finally, the third-degree map (Fig. 5), a complex hyperbolic surface with an explained variation of 60 percent, shows a distinct difference in the northern and southern regions. In the southern region, a basin-like low predominates with values increasing northward with a contour-closure value of 17 percent in the north. Thus, in terms of reclamation, a domal-type landform is suggested for the north and a basin-type feature for the south. Of the three surfaces of fit examined, the third-degree plane appears more acceptable because of its 35 percent improvement of fit. The selection of trend surfaces deemed most suitable for land treatment design must be further weighed, however, by the nature of spoil variation, climate, vegetation, and related land resource constraints.

LITERATURE CITED

1. Harbaugh, J. W. Trend-surface Mapping of Hydrodynamic Oil Traps With the IBM 7090/94 Computer. Colo. Sch. Mines Q. 59(4): 557-578. 1964.

2. Keefer, W. R., and P. W. Schmidt. Energy Resources Map of the Powder River Basin, Wyoming and Montana. Misc. Geol. Invest. Map; Map I-847-A. U.S. Geol. Surv. 1973.

3. Krumbein, W. C., and F. A. Graybill. An Introduction to Statistical Models in Geology. New York, McGraw-Hill Book Co., 475 p. 1965.

4. Lustig, Lawrence K. Trend-surface Analysis of the Basin and Range Province, and Some Geomorphic Implications. U.S. Geol. Surv. Prof. Pap. 500-D, 70 p. 1969.

5. McIntyre, D. B. Program for Computation of Trend Surfaces and Residuals of Degree 1 Through 8. Seaver Lab. Dep. Geol. Pomona Coll., Claremont, Calif. 1963.

6. O'Leary, Mont, R. H. Lippert, and O. T. Spitz. Fortran IV and Map Program for Computation and Plotting of Trend Surfaces for Degrees 1 Through 6. Kansas Geol. Surv. Computer Contrib. 3. 1966.

7. Peikert, E. W. IBM 709 Program for Least-squares Analysis of Three-dimensional Geological and Geophysical Observations. Off. Naval Res. Geogr. Branch, Tech. Rep. 4, ONR TASK No. 389-135. 1963.

8. Wentworth, Chester K. A Simplified Method of Determining Average Slope of Land Surfaces. Am. J. Sci. 20: 184-194. 1930.

9. Whitten, E. H. T. A Surface Fitting Program Suitable for Testing Geological Models Which Involve a Really-distributed Data. Off. Nava Res., Geogr. Branch, Tech Rep. 2, ONR TASK No. 389-135. 1963.

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HYDROLOGIC IMPACTS OF COAL MINE EFFLUENTS AND SPOILS LEACHATES

Wayne A. Van Voast*
Robert B. Hedges
Gordon K. Pagenkopf

INTRODUCTION

Concern for southeastern Montana's environment has expanded during the 1970's to generate hydrologic and other types of environmental research examining the mining and development of coal. Objectives of research in hydrology are to understand and predict the hydrologic effects of strip mining in the Fort Union Coal Region (Figure 1). Such understanding and predictive capability will enable applications of mining and reclamation techniques to minimize or eliminate development-related hydrologic problems.

Satisfactory completion of the research requires tremendous volumes of basic hydrologic data and careful analyses of mining-related activities. Well and spring inventories in the Birney-Decker area (Figure 1) by the U. S. Geological Survey, Water Resources Division (2), have provided much baseline data for coal-related hydrologic research. Additional hydrologic data for active mine areas, such as at Colstrip and Decker, are being combined with laboratory experimental work to develop predictive capabilities for application to future mine areas. The studies are intended to culminate in a useful product to planners, engineers, and local residents of the Fort Union Coal Region in Montana and adjacent states.

Research has thus far established that the main hydrologic effects of strip mining of coal will be changes in ground-water flow patterns during mining, and changes in ground-water quality after mining is completed. Alterations of flow patterns during the mining operations will occur locally in aquifers peripheral to the mines. Alterations of ground-water quality will occur within and downgradient from mined and reclaimed areas.

The simple acknowledgment of hydrologic effects has little meaning without establishment of their significance. Objectives of this report are to describe the current status of research in water-quality effects of mining, to add perspective to current knowledge, and to define the directions of the research program.

MINE WATER QUALITY

Almost all water-quality data from mined areas in Montana have been collected in the Rosebud Mine at Colstrip (Figure 2). From 1924 through 1958, the mine was operated by Northwestern Improvement Co. The relatively wide southeastern end of the mine has been developed by Western Energy Co. since 1968. Ground

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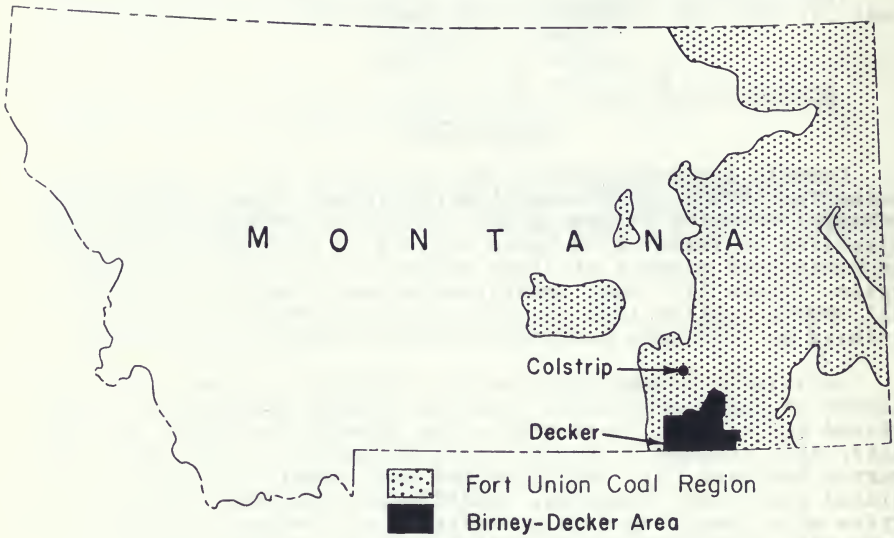

Figure 1. Locales of Fort Union coal-related hydrologic research in Montana.

water in nearby aquifers flows into the mine area from the north and west. Entrance rates of these waters are not great; there is no abundance of ground water in the mined and backfilled areas or in the active mine pit. Waters have been obtained for chemical analyses from wells established specifically to determine hydrological characteristics of spoils, and from ponds in portions of the mined area. Values shown in figure 2 are specific-conductance values for waters from spoils; these values equal about .9 of the dissolved solids concentrations. Specific-conductance values of waters in the spoils range from about 2000 µmhos/cm (micromhos per centimeter) in the relatively young spoils in the southeastern corner of the mine, to more than 5000 µmhos/cm in the older spoils near Colstrip. The apparent relationship of more highly mineralized waters occurring in older spoils cannot yet be explained. Laboratory data thus far indicate little relationship between ages of spoils and the degrees of mineralization of waters within them (5).

They hydrology of the mined area is so complex that ground-water flow patterns have not yet been specifically established. Near the northwestern end of the mined area, where more mineralized waters apparently occur, correspondingly mineralized waters have been detected occasionally in East Fork Armells Creek in periods of extremely low or no flow. It is assumed that these waters have originated in Rosebud spoils and have migrated northwestward as ground-water to the creek (5). Similar waters have not yet been detected upstream from the mine area. Other creeks having head waters in the spoils area (not shown on figure 2) include the eastward flowing ephemeral streams, North and South

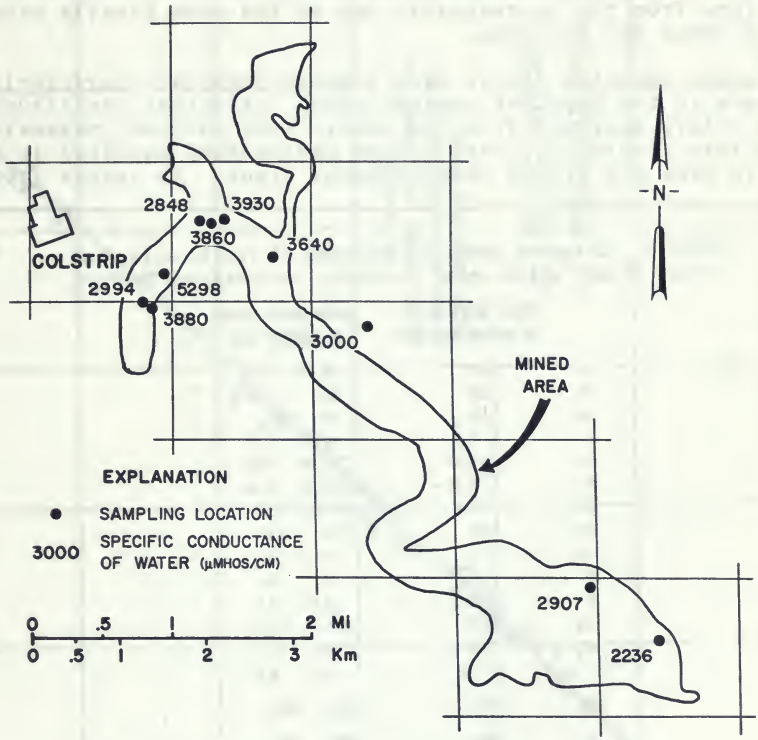

Figure 2. Specific-conductance values for waters from Rosebud Mine spoils, southeastern Montana.

Forks of Cow Creek, and Hay Coulee, No waters of abnormally high dissolved-solids concentrations have been detected in these streams.

An overview of water quality for the Rosebud Mine and wells and springs in a large surrounding area (Figure 3) shows that water in the mine spoils is indeed generally more highly mineralized than waters from aquifers not distrubed by mining (5). Of the range of dissolved-solids and specific-conductance values for waters from unaffected aquifers, values for spoils waters correspond with the approximate upper half. However, only values for waters from the northwestern end of the mine greatly exceed most of those for the area.

Waters from the spoils have similar chemical characteristics to waters in the adjacent unmined area. Principal constituents in all waters analysed from the spoils were calcium, magnesium, and sulfate (Table 1). Waters from undisturbed aquifers in the Colstrip area are of two main chemical types. In waters from

Table 1. Selected chemical analyses of spoils water and other ground waters near Colstrip, southeastern Montana.

	SPOILS WATER TYPICAL OF ROSEBUD MINE AREA	GROUND WATERS TYPICAL OF COLSTRIP AREA	
Ca	421	250	14
Mg	306	281	3.4
Na	119	57	603
K	9.9	7.8	3.6
Fe	0.02	0.04	0.65
Mn	0.70	0.03	0.02
SiO_2	17.3	16.2	7.1
HCO_3	333	530	413
CO_3	0	0	0
OH	0	0	0
Cl	14.3	8.2	7.9
SO_4	2166	1404	978
NO_3	10	0.5	0.1
F	0.0	0.1	0.4
TDS	3398	2555	2032
Sp.C.	3510	2720	2610
SAR	1.1	0.6	37.5
pH	7.7	7.7	8.0

CONSTITUENTS IN MILLIGRAMS PER LITER
SP.C. (SPECIFIC CONDUCTANCE) IN μMHOS/CENTIMETER

most shallow aquifers below the stratigraphic units being mined, principal constituents are sodium, bicarbonate, and sulfate. Waters from stratigraphic intervals equivalent to or higher than the mine area are chemically similar to the waters in the spoils. From these comparisons it can be seen that waters entering the mine area are not changed in their chemical type; if anything, the existing principal constituents in solution are increased. This relationship is compatible with the assumption that the

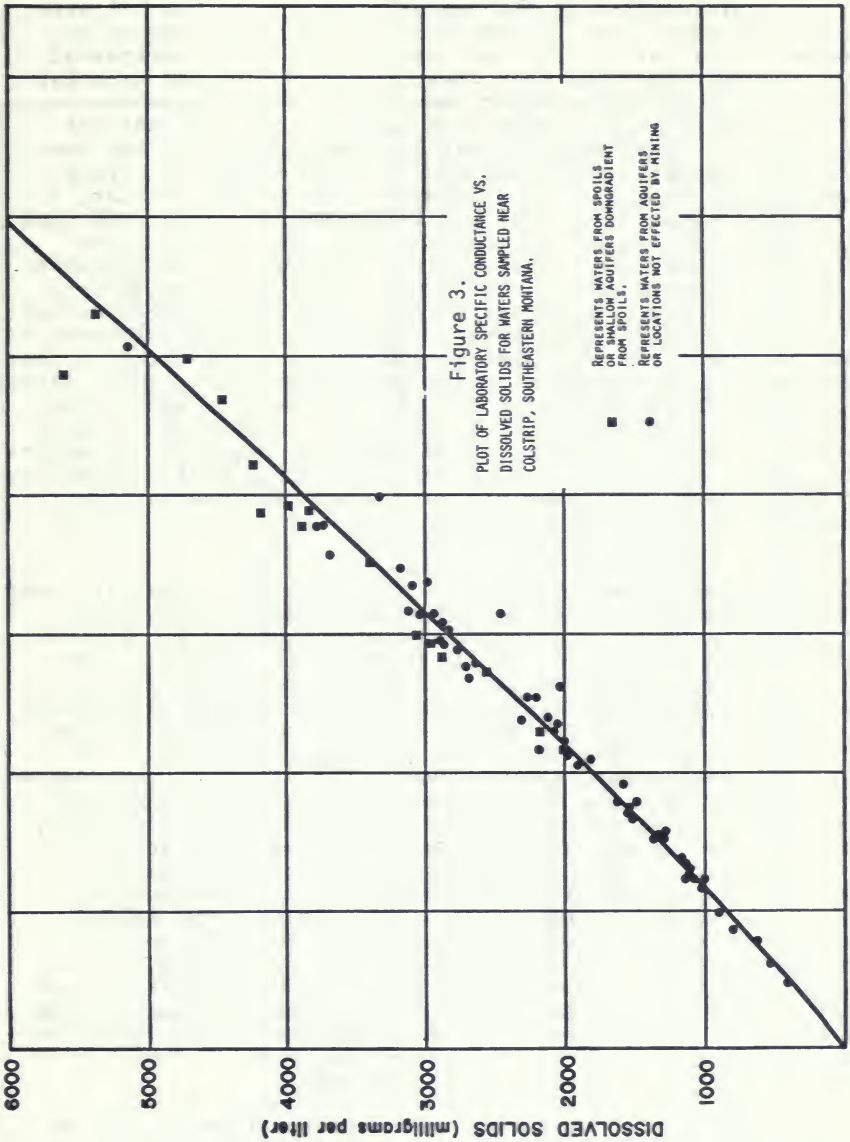

Figure 3.
PLOT OF LABORATORY SPECIFIC CONDUCTANCE VS. DISSOLVED SOLIDS FOR WATERS SAMPLED NEAR COLSTRIP, SOUTHEASTERN MONTANA.

quality of ground water is determined by the minerals available for dissolution, and that these minerals are more available for dissolution in the disturbed overburden materials than they are in the undisturbed strata.

Hydrologic studies at the Decker mine area (Figure 4) were begun in 1970 when a pre-mining study was completed and an observation network of 14 wells was established in an peripheral to the proposed mine area (4). Research in the Decker area has provided much information about changes in water levels and pressure surfaces in an active mine situation but has not yet provided data on post-mining hydrologic conditions; in the context of this report, only water-quality data collected during the mining operation will be discussed. At the Decker Mine, a coal bed approximately 50 feet thick is being removed. The coal bed is also a significant aquifer for the area. Flow in the aquifer is eastward and northeastward from uplands to the watercourse of the Tongue River. The first cut of the mine intercepted this natural ground-water flow and is diverting it directly to the Tongue River Reservoir at the cut's easternmost end. It must be emphasized that underground waters intercepted by the mine cut and pumped directly to the river and reservoir are waters that have discharged naturally to the river long before mining began. These waters are now collected in a sump at the easternmost end of the mine and from there they are pumped to the watercourse. The sump is deep enough below the river that waters also enter from beneath the river's flood plain. The mine effluent is therefore a combination of waters from the coal-bed aquifer and waters from alluvium along the river.

When mining began in 1972, the mine effluent flowed at about 350,000 gallons per day (4) and consisted almost entirely of waters from the coal. Chemically the effluent was very similar to waters sampled from local wells (Figure 5). As mining proceeded, discharge from the coal-bed aquifer decreased gradually as hydrostatic pressures adjusted to new base levels established by the first mine cut. The amount of water being induced from the flood plain probably held relatively constant because of nearby recharge supplied by the river. The effect of the reduced volume of water from the coal-bed aquifer has been a reduction in the chemical constituents in the mine effluent. Since 1972, concentrations of chemical constituents in the effluent has decreased sporadically but continuously. A rough approximation of the changes in chemical concentrations is a 40 percent reduction in dissolved solids, bicarbonate, sodium, and sulfate. These findings directly negate one of the predictions published by the Montana Bureau of Mines and Geology (4). There, it was estimated that mine-effluent rates would gradually increase and finally be double the first year's rate. These chemical differences indicate that ground-water discharge from the coal to the mine must have decreased by at least 40 percent. There is no indication that this trend will not continue.

Minor chemical constituents in the mine effluent, such as calcium and magnesium, have varied sporadically through the period of mining with no apparent net increase or decrease. Calcium and magnesium have been found in concentrations between about 8 and 80 milligrams per liter; in most analyses, magnesium has been present in slightly greater concentrations than calcium.

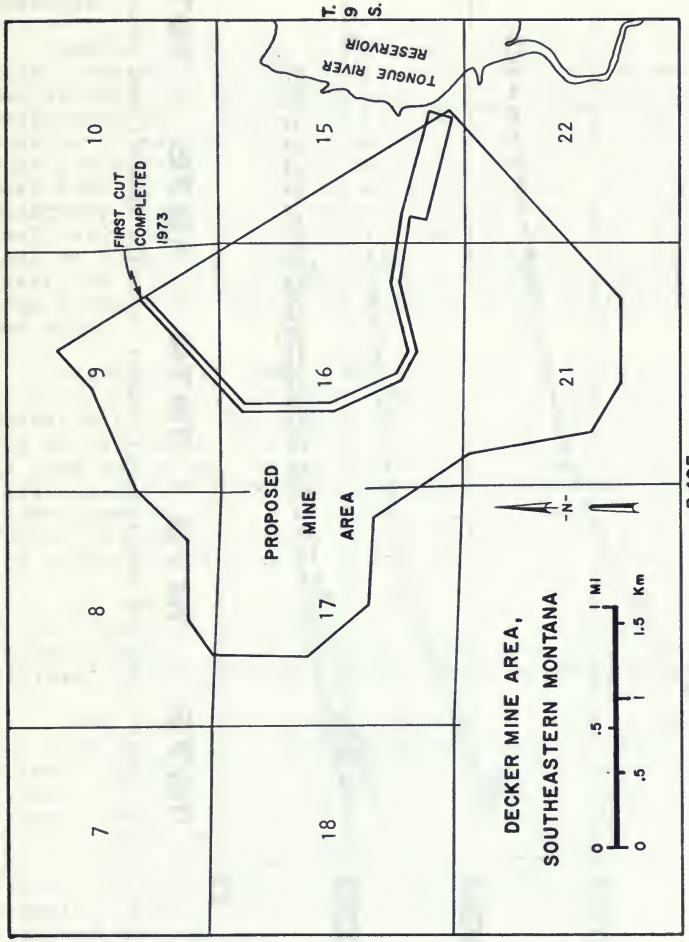

Figure 4. Decker coal mine along the Tongue River, southeastern Montana.

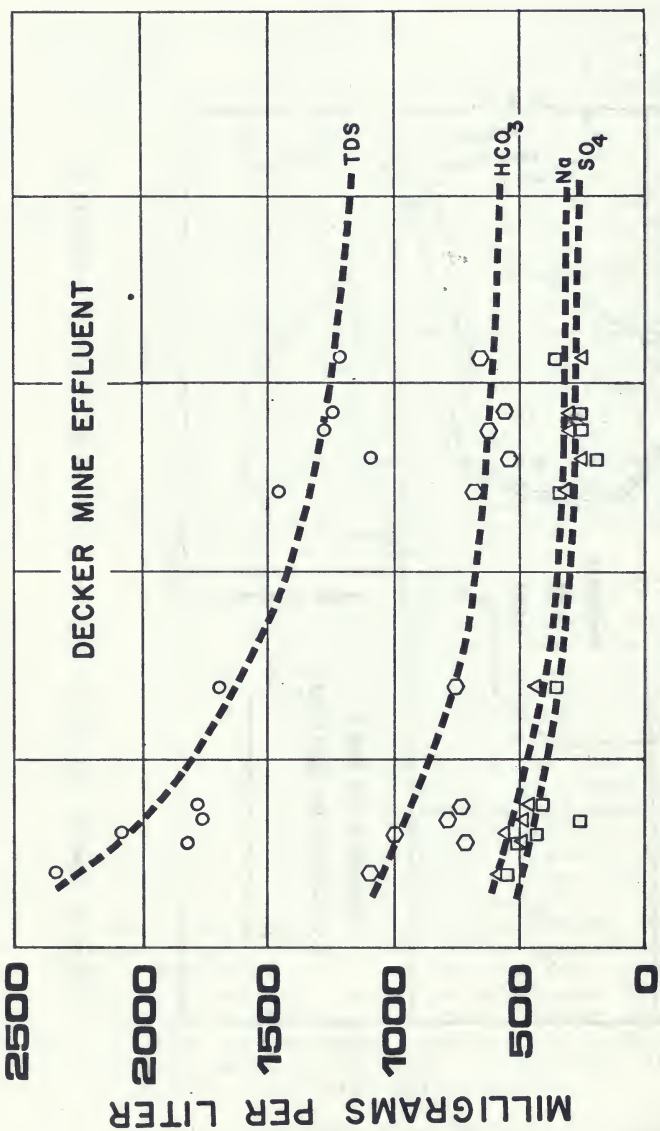

Figure 5. Concentrations of total solids and selected constituents in Decker Mine effluent since mining began.

The result of continuously decreasing sodium concentrations and non-corresponding changes in calcium and magnesium has been a strong decrease in SAR (sodium adsorption ratio) values (Figure 6). The SAR values presented in the first hydrologic report of the Decker Mine (4) have decreased by more than 50 percent. The report stated that effluent waters would not be useable for irrigation if needed for reclamation of the mine spoils. Since that time, the SAR values have reduced such that irrigation is probably feasible.

Another chemical constituent, nitrate, has occurred in sporadic concentrations in Decker mine effluent waters (Figure 7). The nitrate concentrations have varied from less than one mg/l (milligram per liter) to more than 110 mg/l. The total concentration of nitrate discharged to the river is probably very low; most concentrations found have been less than 20 mg/l, and many less than 10 mg/l. The occurrence of these abnormally and sporadically high nitrate concentrations may be attributed to residual nitrates from explosives used in blasting overburden and coal or to highly soluble nitrate compounds in the disturbed materials. Similar anomalous concentrations of nitrate have been found occasionally in waters in the active pit of the Rosebud Mine.

Water-quality data made available through baseline collections by the U.S. Geological Survey enable a perspective of Decker mine effluent water relative to other ground-waters of the Birney-Decker area (2). For example, of 231 samples obtained from wells and springs (Figure 8), about 90 percent had specific-conductance values greater than 1000 µmhos/cm and SAR values greater than 2. Specific-conductance values of about 70 percent of these waters, and SAR values for about 60 percent of the waters, were greater than those of the effluent (Feb. 2, 1975).

The Tongue River is a major ground-water discharge lineament in the Birney-Decker area and receives effluent from the undisturbed aquifers as well as the mine; chemical impact of the mine's effluent upon the river should cause no environmental concern.

When mining has been completed at Decker, waters of different chemical quality may begin entering the river and reservoir. Actual conditions will be decided by final reclamation and mining plans. If the final mine cut is backfilled such that pre-mining ground-water flow patterns recur, the mine spoils will generate ground waters more highly mineralized than those of the pre-mining system. These waters will enter the river system at approximately the same rates as did waters before mining began. The potential significance of the new conditions is currently being examined and argued.

LABORATORY SIMULATIONS

Predictions of post-mining water qualities will require laboratory simulations representative of field conditions. One way to develop and test this expertise is to conduct laboratory leach tests using spoils and overburden from mined areas in attempts to simulate chemistry of spoils waters obtained in the field. The method has been demonstrated with apparent success for mine spoils in Colorado (1). In the Colorado research,

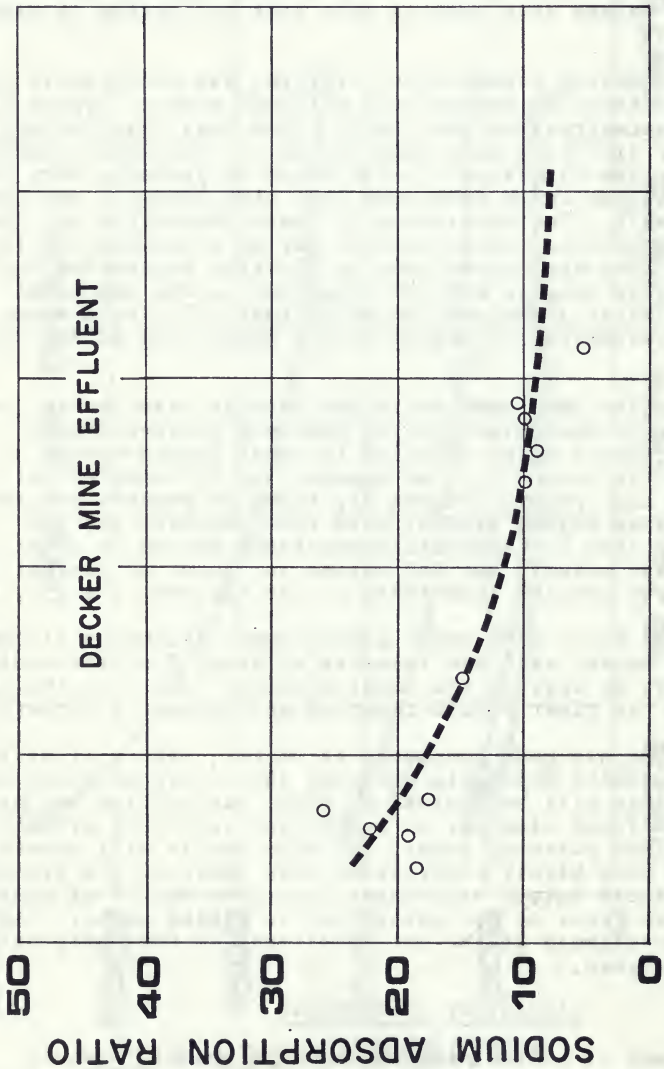

Figure 6. Sodium adsorption ratios determined for Decker Mine effluent since mining began.

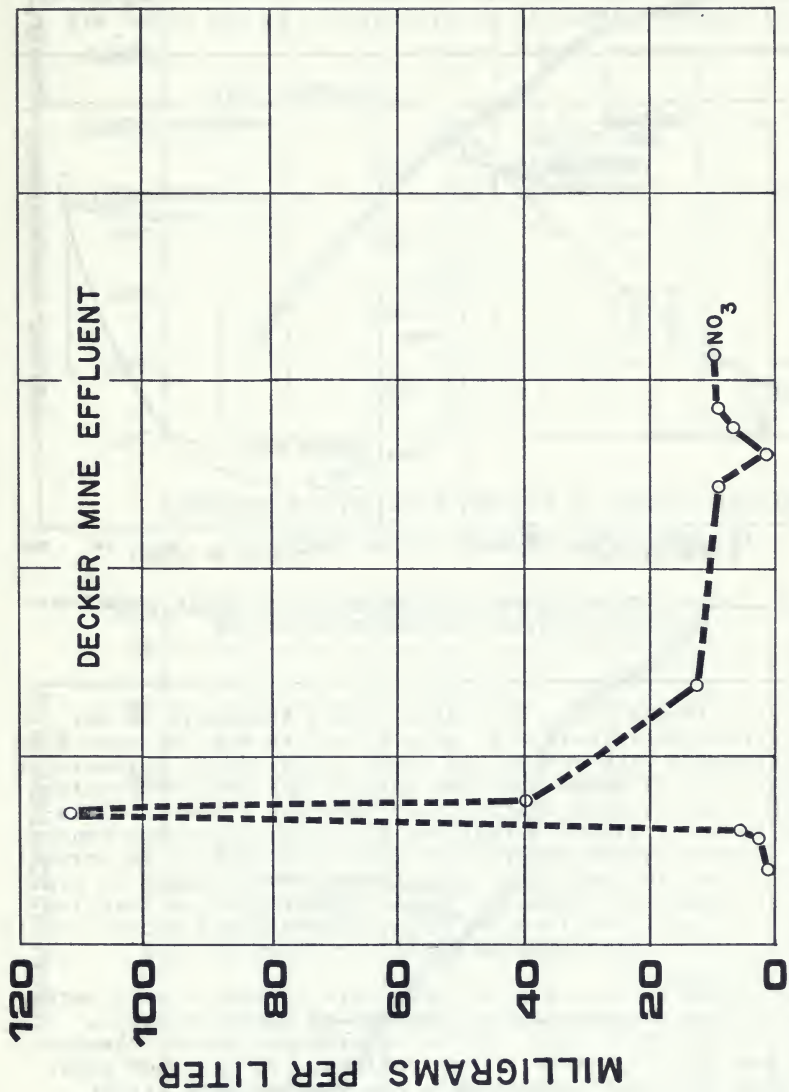

Figure 7. Concentrations of nitrate in Decker Mine effluent since mining began.

distilled water was combined with spoils materials to produce saturated pastes. Waters extracted from the pastes were chemically comparable to field-collected spoils waters. Dr. Gordon Pagenkopf, a coauthor on this report, has attempted similar leach experiments with overburden from the Decker and Rosebud mine areas (Figure 9). As part of the Montana research, waters from local aquifers known to be discharging to the mines are

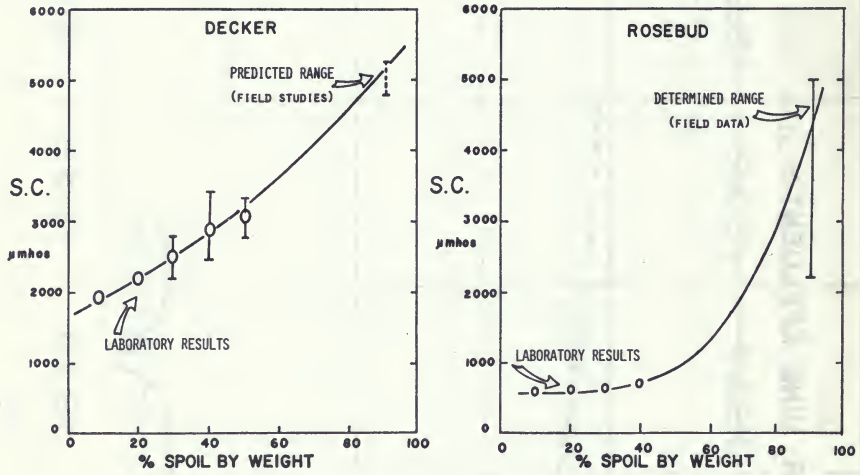

Figure 9. Projections of laboratory-produced spoil-leachate conductances to field predictions and determinations (3).

utilized as solvents (3). Saturated pastes seemingly do not simulate field conditions here, so projections must be made from leach experiments with spoils and water in different percentages of combination. Although the experiments have not yet provided conclusive results, some concepts are becoming evident. Relationships shown in figure 9 indicate that specific-conductance values of spoils waters under field conditions (about 90 percent spoil and 10 percent water, by weight) can be estimated by projections of laboratory values. Another indication is that runoff from mined areas will not be highly mineralized because spoil-water ratios for runoff will be small.

A complication to the laboratory work is that spoils waters occur in the field under various degrees of mineralization. Laboratory projections will have to be directed toward chemical ranges rather than specific concentrations. To approach these ranges, many additional experiments are planned with larger numbers of overburden samples and more diverse spoil-to-water ratios.

SUMMARY

The water-quality work that has been described in this

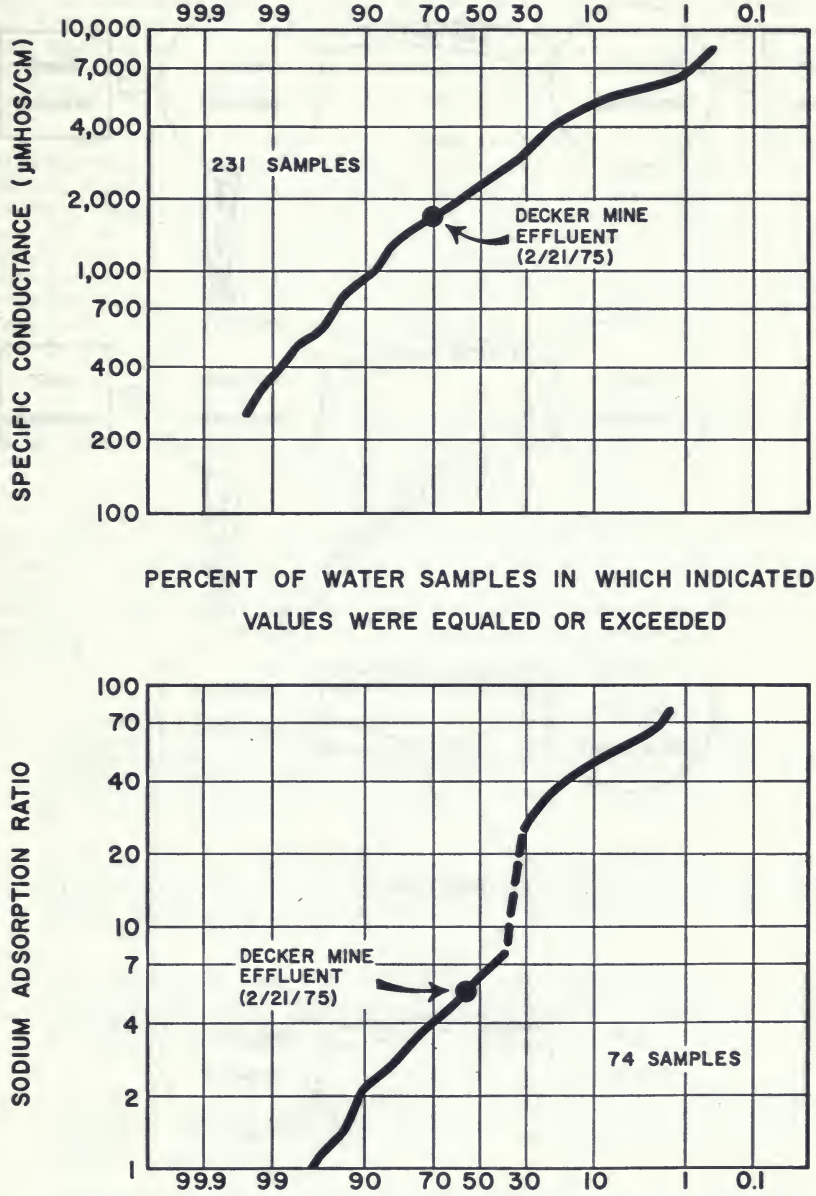

Figure 8. Statistical distributions of water-quality parameters for samples of ground water from the Birney-Decker area, southeastern Montana.

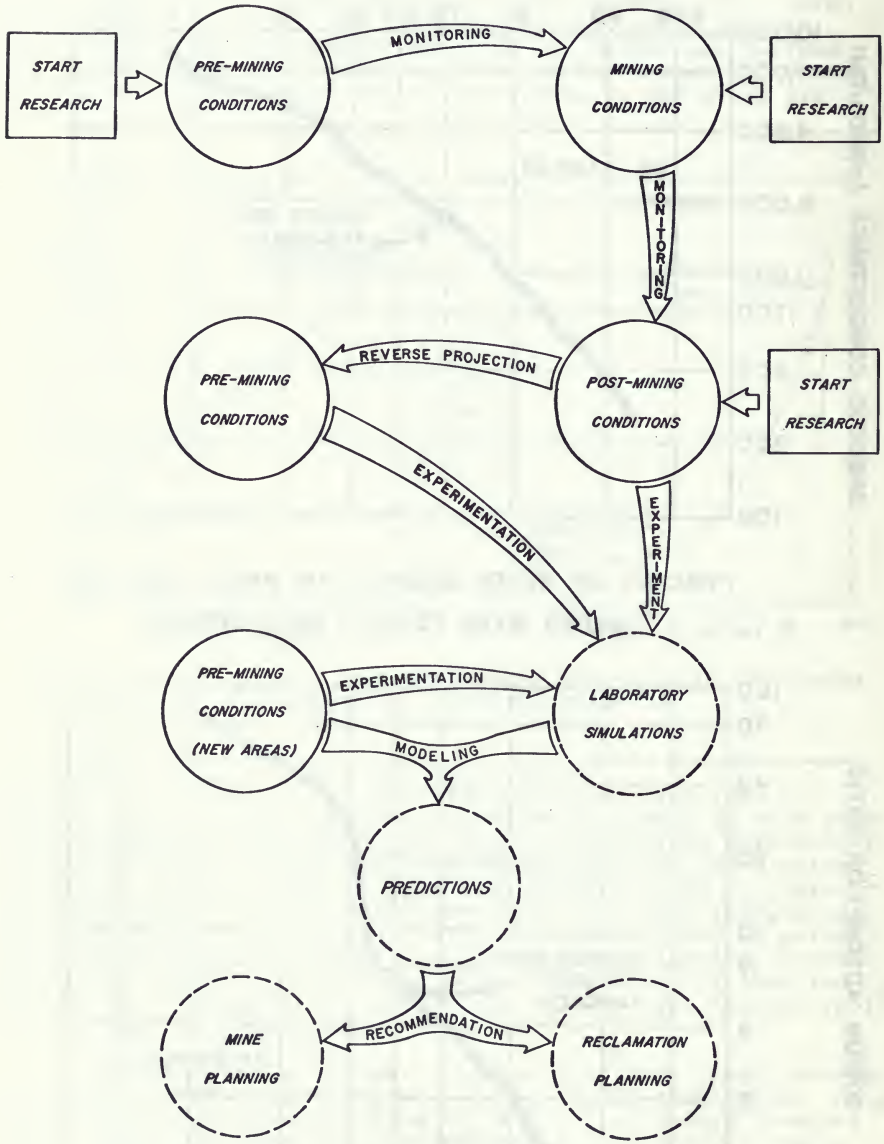

Figure 10. Coal-related hydrologic research: options, directions, and objectives.

report is only a portion of a larger and more comprehensive research program. Studies have been initiated in three phases of the coal-development cycle (Figure 10). These are evaluations of pre-mining, mining, and post-mining hydrologic conditions. All approaches require necessary data and are directed toward a common objective. That is the development of predictive capabilities as input for mine and reclamation planning.

Some of the studies that were initiated in areas before mining began have now evolved to studies of hydrologic conditions during mining. Examples are projects at Decker and near Sarpy Creek. Research that began during mining operations at the south end of the Rosebud Mine has evolved to research of post-mining conditions. The pre-mining and mining studies determine original and transitional conditions but require unreasonably long periods of time to generate post-mining data. To speed a satisfactory conclusion to the research, studies of areas already mined are now in progress.

With all three approaches to the problem, and with the development of simulation techniques, potential hydrologic effects of future mine operations will become predictable.

ACKNOWLEDGMENTS

Acknowledgments must be made to the agencies, companies, and eastern Montana residents who have provided financial, technical, and mechanical support to the research. Specific gratitude for funding is owed the U.S. Environmental Protection Agency, the U.S. Geological Survey, the Office of Water Resources Research, Decker Coal Co., Western Energy Co., and the State of Montana.

LITERATURE CITED

1. McWhorter, D. B., Skogerboe, R. K., and Skogerboe, G. V., Potential of Mine and Mill Spoils for Water Quality Degradation, Proceedings of American Water Resources Association Symposium on Water Resources Problems Related to Mining, Golden, Colo., 1974.

2. Northern Great Plains Resource Program, Ground-water Subgroup, Shallow Ground Water in Selected Areas in the Fort Union Coal Region, U.S. Geol. Survey open-file report no. 74-371. 1974.

3. Pagenkopf, G. K., Whitworth, C., and Van Voast, W. A. Influence of Spoil Material on Ground-water Quality, Paper presented before American Chemical Society, Division of Environmental Chemistry, Philadelphia, Pa., April, 1975.

4. Van Voast, W. A. Hydrologic Effects of Strip Coal Mining in Southeastern Montana--Emphasis: One Year of Mining Near Decker. Montana Bureau of Mines and Geology Bulletin 93, 24 p. 1974.

5. Van Voast, W. A., and Hedges, R. B., Hydrology of Western Energy Company's Probable Mine Areas Near Colstrip, Southeastern Montana. Montana Bureau of Mines and Geology open-file report, Butte, Montana 1974.

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MINE SPOIL RECLAMATION RESEARCH AT THE BELLE AYR MINE, NORTHEAST WYOMING

Howard K. Orr*

Nowhere does present concern for our outdoor environment seem more vocally and forcefully expressed than in connection with mining and processing of the gigantic surface-minable reserves of lignite and sub-bituminous coal in the Fort Union area of the Northern Great Plains. The so-called Wyodak beds, a strip averaging about 5 miles wide by 100 miles long on the east fringe of the Powder River Basin in Campbell County, northeast Wyoming, contains in excess of 19 billion tons of surface-minable coal (less than 200 feet of overburden). This is more tonnage than in any other known area of comparable size in the entire United States, and perhaps in the World. Present and projected surface mining operations, if implemented, can be expected to drastically disturb a large part of this area, which is about 10 percent of the area of Campbell County and 0.5 percent of the State of Wyoming.

Revegetation is one of the most critical concerns relative to surface mining of these vast coal resources. Considerable guiding information is already available concerning adaptable herbaceous plant species and planting techniques. But it is our contention that a variety of woody plant species is needed, together with the lower growing herbaceous species, for esthetics, for wildlife habitat, and for site amelioration.

The Rapid City Unit of the Rocky Mountain Forest and Range Experiment Station has begun research involving adaptability and establishment of tree and shrub species. Present research in the coal region is limited to one mine--the AMAX Inc., Belle Ayr Mine 16 miles south-southeast of Gillette, Wyoming--in cooperation with AMAX, the University of Wyoming, and SEAM.

Ground-water effects of surface mining are an especially cogent concern in the Wyodak outcrop area because of the exceptional thickness of the coal beds (70 feet average) and indications that the beds themselves or the zones immediately above are the primary shallow ground-water aquifers. These supplies have met limited domestic and livestock needs of the past. Will they be seriously disrupted by mining? We are cooperating with the Wyoming Water Resources Research Institute and AMAX in study of ground water in the Belle Ayr vicinity--water levels, movement, and storage as mining progresses--and are working on the development of a regional program.

Dominant vegetation in the Belle Ayr vicinity is a wheatgrass--needlegrass complex, according to Kuchler (2). Low shrubs, mainly sagebrush, are also present. Average annual precipitation is in the 13-14 inch range. The vegetation is basically the same

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over the entire Wyodak region, extending from about 30 miles north of Gillette south along nearly the entire length of Campbell County into northern Converse County. Average annual precipitation is 1 to 3 inches more north of Gillette than at Belle Ayr, however, a difference sufficient to be of great significance in terms of rehabilitation potential.

Topography of the general area has been described by Aandahl (1) as undulating rolling to undulating hilly, with soils loamy to clayey, shallow, underlain by interbedded sandstones, shales, and silt stones at 20 to 60 inches depth.

The initial cut at the Belle Ayr mine is along Caballo Creek, where overburden is shallowest. The Creek was diverted by diking. Examination of the cut reveals some of the general characteristics of the overburden that are important in arranging replacement and some clues to characteristics of the ground water system of the area.

The coal here is at or near the top of the Fort Union formation. Overburden is of the Wasatch formation, which is described as 1,050 to 3,500 feet thick in the central part of the basin, and composed largely of shale, sandstone, and coal. Overburden materials at the mine site are basal Wasatch, and are composed of shales and weak sandstones with scattered clay lenses. Scoria pockets are found near the outcrop. Overburden is removed in layers with a power shovel and truck haul system. The upper 5 to 10 feet are used as the finish layer of the replaced overburden.

Some ground-water implications are becoming clearly observable as sequential mine development is being followed. Groundwater inflow that accumulates in the pit is pumped over the barrier dike into the main channel. Direct evidence of intercepted ground water includes visible water entering where the pit intercepts a shallow side valley. This water is coming out about halfway down the visible coal bed. There is less evidence of free water toward the surface outcrop.

Overburden is hauled to one side of the pit as coal is hauled from the other. Total coal thickness is about 70 feet. By summer 1974, the pit was large enough to start backfilling. Gray shaley material considered poor for surface emplacemnt was dumped in the excavation, while other material was surface dumped and some was used as spoil finish. By this time the fill extended well across the initial cut toward the toe, where unoxidized coal of minable quality pinched out. By early spring 1975 the toe of the cut was filled to near or above the original land level and the fill was being blended into the diversion dike. The upper strata of overburden were being hauled from the pit northeast to a dump (in the outcrop area) which will be shaped and blended into the existing prairie landscape.

Facilities for ground-water study include a network of wells to the top of the coal, through the coal, and below the coal. Continuous recorders are placed on key wells, and several pairs are arranged for standard pumping tests for determination of transmissibility and specific capacity. Additional water study facilities include several Parshall flumes on main Caballo

Creek, both up stream and downstrem from the mine, and water-level recorders on natural controls.

Tree and shrub adaptability and establishment is being studied on a fill area adjacent to the initial cut. The surface lift was laid by end dumping on the travel level. Thereafter, the only traffic was a blade-equipped crawler tractor to level and finish the final lift, followed by tillage and planting equipment.

Prior to plot layout, the area had been drilled with a mixture of western wheatgrass, green needlegrass and four-wing saltbush through cooperation of AMAX and the Soil Conservation Service. The tree--shrub plot as originally laid out involves 7 species, 1 row of 45 plants of each species in each of 5 blocks, plants 6 feet apart in rows 8 feet apart. Choice of species was based on best available experience regarding most likely survival, and multiple benefits, especially for wildlife food and protection. Species planted were: green ash, Russian olive, silver buffaloberry, Siberian peashrub, American plum, Rocky Mountain juniper, and ponderosa pine. Moisture conditions were excellent at time of planting in May 1973.

In June when the spoil in the plot area was sampled for physical properties, planted stock appeared in excellent condition and newly planted grasses were showing well. By late July, however, the planted materials were nearly obscured by a thrifty stand of Russian thistle. The same shrub and tree species were interplanted in the same arrangement in 1974. Survival percentages are shown in Table 1. In both years the survivals appeared

Table 1. Survival percentages of planted trees and shrubs

Species	Planted 1973		Planted 1974
	Counted in Sept. 1973	Counted in Sept. 1974	Counted in Sept. 1974
Green ash	99	43	41
Russian olive	84	35	23
Ponderosa pine	59	11	32
Rocky Mountain juniper	52	39	45
Silver buffaloberry	44	9	29
American plum	31	7	9
Siberian peashrub	17	8	39

to be related to precipitation received. From time of installation in mid June 1973 to the end of the year, total precipitation was 8.2 inches. In the corresponding 1974 period only 5.8 inches of precipitation fell. During a hot period from August 11, 1974

to the time of survival count in September, only 0.03 inch of rain was recorded. Total 1974 calender-year precipitation was only 10.4 inches. In September 1974, the most prominent vegetation was again Russian thistle plus some of the seeded fourwing saltbush.

Preliminary analyses of physical and chemical characteristics of the spoil did not reveal any obvious severely inhibiting factors. Average texture of samples collected to 54 inches depth in 1973 was sandy clay loam and surprisingly uniform. In terms of physical characteristics the spoil appears well suited for vegetative growth. Overall bulk density was 1.55. The saturation moisture content (total pore volume) of 42 percent was made up of 23 percent micro pore volume and 19 percent macro pore volume. Wilting point moisture content was 11 percent. The spoil material on the experimental plot is moderately saline but alkalinity is low (pH 6.6 to 8.6). The sodium adsorption ratio (SAR) ranges up to only about 3. Hence, dispersion and resultant surface sealing associated with highly sodic conditions does not appear to be a problem.

Other concerns in the project area include wildlife. Deer are abundant, as are antelope. The antelope, particularly, seem unafraid and not greatly disturbed by the mining activity. Waterfowl and shore birds are numerous along the main waterways and on ponds. Among a variety of non-game birds sighted in the area has been the great horned owl, nesting in the scoria banks adjacent to Caballo Creek, close to the mining activity. Evidence of small burrowing animals has been seen, and research plans are underway to reintroduce several species, to evaluate their effects on spoil structure.

SUMMARY

Revegetation research with shrubs and trees at Belle Ayr can be classed as moderately successful so far. The most apparent limiting factor has been too little moisture. Stress conditions are high. Risk of failure in any given year is high enough to warrant additional effort and expense. Research approaches in planning stages include trickle irrigation, containerized planting stock, and measures to conserve moisture such as cross-wind furrowing and mulching. All of these measures can be expected, in some degree, to also control erosion and movement of sediment from mine spoil areas.

LITERATURE CITED

1. Aandahl, A. R. Soils of the Great Plains--A Detailed Map of the Soil Associations of the Great Plains. P. O. Box 81242, Lincoln, Neb. 68508. 1972.

2. Kuchler, A. W. Potential Natural Vegetation of the Conterminous United States. American Geographical Soc. Special Pub. 36. 1964.

* * *

DEVELOPMENT OF A PRE-MINING GEOLOGICAL FRAMEWORK FOR LANDSCAPE DESIGN RECLAMATION IN NORTH DAKOTA

Stephen R. Moran, Gerald H. Groenewold,*
Leroy Hemish and Curtis Anderson

INTRODUCTION

Two principal environmental concerns associated with the large-scale mining of lignite in western North Dakota are the preservation of agricultural productivity and the maintainence of high-quality groundwater supplies.

The first of these concerns, the return to agricultural productivity, is widely felt and has been recognized by Governor Link as the most important factor in determing the type and rate of lignite development in North Dakota. The stated reclamation goal for the state is a return to a level of productivity no less than 100% of the level prior to mining.

Just as is the case throughout the areas farther to the west and south, there is concern in North Dakota that precious water supplies not be damaged by coal development. In many areas, lignite beds may serve as important aquifers or play important roles in groundwater recharge. There is concern that the amount of water available may be adversely affected as a result of coal development. In other areas there is concern that the total dissolved solids of surface water and groundwater may be increased by leaching from spoil materials or waste-disposal facilities.

Working through the Mined Land Planning Group, a group of university, state, and federal scientists appointed by Governor Link, the North Dakota Geological Survey (NDGS) and North Dakota Agricultural Experiment Station have begun research to develop the methodology needed to achieve these reclamation goals. These studies, which have been funded by the Old West Regional Commission, have had the support and active cooperation of a number of mining companies and potential coal developers, especially the North American Coal Corp. and the Natural Gas Pipeline Company of America.

Three subprojects of the overall study are being conducted by the Agricultural Experiment Station. These studies are related to revegetation, root-zone hydrology, and the chemical and physical characterization of overburden materials. The fourth subproject is being conducted by the North Dakota Geological Survey. This study is directed at developing techniques to determine the detailed stratigraphy of overburden and utilizing of the data in planning reclamation procedures. The NDGS study is also designed to examine techniques for monitoring groundwater conditions for regulatory purposes.

One principal that emerged very early in these studies is

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that each mining area must be treated individually. Legislation and regulation can define a set of general guidelines within which each site can be evaluated, but because of the variability between areas in geology, climate, soils and hydrology it is not possible to write specific regulations for reclamation throughout the state.

CONCEPTUAL FRAMEWORK FOR RECLAMATION

We will first explore the ideas that underlie the approach and philosphy of NDGS reclamation research. This is an idealized, theoretical analysis of the direction that our thoughts trend.

Soil Repair

Initial work on reclamation of strip-mine spoils was based on a philosphy of "soil repair" or "salvage reclamation." That is to say, mining was begun, carried out, and completed without regard to any further use of the area. Reclamation was not begun until mining was completed. The reclamation officer attempted to salvage what he could on the spoil banks. Plants that could be grown on steep slopes in poor material were planted. The next step in developing the modern concept of reclamation was to partially level the steep slopes, but still reclamation was a salvage operation that was begun after the mining was finished.

Soil Design

Modern reclamation in North Dakota is a far more sophisticated procedure that begins far earlier in the mining process. By law, the operator must determine the suitability of soil and other overburden material for supporting vegetation and take steps to segregate and save as much as 5 feet of this material before mining. It has been stated that "reclamation begins with the placement of the first bucketful of overburden removed from above a vein of coal on the area from which the coal has been removed" (8). We would carry it even farther back: reclamation begins as the mine is being planned. The reclamation plan is synonomous with the mining plan.

Landscape Design

In order to reclaim a mined area, not only the soil but the entire landscape must be redesigned. The makeup of a landscape, in the sense we are using it, and the processes acting on and in it must be explored to understand the reason for this.

Landscape, as we are using it, includes the substance, as well as the form of the earth's surface. It includes the morphology of the surface, the soils on that surface, the structure of the rock and sediment beneath the surface, and the water that moves over and beneath the surface. The form of the surface, the soils on the surface, and the hydrologic regime beneath and upon the surface represent a more or less delicately balanced equilibrium with the forces acting on and beneath that surface. When there is a big enough change in the forces acting on a landscape, (for example during a climatic change) the landscape adjusts itself to a new equilibrium that is stable under these new

conditions (2). During the Dirty Thirties, when the climate was warmer and drier than it is today, vegetation cover was decreased on hillslopes throughout the semiarid Great Plains. Although rainfall was less, runoff from the partially denuded hillslopes was greater, resulting in increased erosion on the slopes. The valley bottoms were clogged with sediment and gully cutting ceased as the floors of the arroyos were aggraded. Dust was blown from these valley floors and deposited on the flat upland surfaces. Through these changes in the rates and the processes of erosion and deposition, the form of the landscape was altered to one better adjusted to the new climatic conditions.

In the same way that a change in the forces acting on the landscape results in the establishment of a new equilibrium landscape, a change in the material making up the landscape will require an adjustment of the landscape. In areas of potential strip mining, the landscape consists of a surfce that is the quasi-stable resultant of the interaction between the climate and the underlying structure, which consists of a series of alternating, relatively thin beds of sediment that differ from each other in physical, chemical, and hydrological properties. Where this landscape is disturbed by surface mining, the horizontal layering is destroyed, and a new, generally more homogeneous, structure results. In some cases, the characteristics of this new landscape may be sufficiently similar to the original landscape that the equilibrium surface form will not be markedly different. However, in most cases, it seems probable that a different morpholohy will be required for stability.

The adjustments within the new landscape can take many forms. Slopes that are too steep will be flattened by erosion high on the slopes, and by deposition on the lower slopes, or by mass movement. Soils that contain organic matter in excess of the amount that can be maintained under the conditions will lose organic matter by oxidization or erosion.

Many of these changes in the landscape are complexly interlinked so that a seemingly minor alteration in one characteristic of the landscape may manifest itself in completely unexpected ways elsewhere in the landscape. For example, a change in the form or permeability of the surface will generally produce a change in groundwater levels and flow patterns. This in turn, can result in changes in slope stability or in water chemistry. These changes can then result in modifications in the landscape that will either amplify or nulify the original change in morphology. Changes in water chemistry and groundwater-flow patterns can result in marked changes in the characteristics of soils.

The goal of landscape-design reclamation is to design and construct a post-mining landscape that approximates, as closely as possible, the equilibrium landscape for the material as it is emplaced following mining. In this way, the natural adjustments that will be made to achieve equilibrium will be minimized. Smaller natural adjustment produces less gullying, surface subsidence, and landsliding, less soil erosion and destruction, less degradation of quality of groundwater and surface water. All of which results in better and cheaper reclamation.

RECLAMATION DESIGN

The first step in reclamation design is to make an inventory of the materials present. It is not possible to evaluate alternative designsof soil or landscape until the designer is aware of what materials he has at hand. The inventory includes a knowledge of the soils, of the geology, and of the hydrology of the area to be mined. In addition, it should include a thorough understanding of the existing state of equilibrium.

The inventory of soils in the proposed mining area involves detailed soil mapping. In addition, analytical data on the chemical characteristics of the soils should be obtained.

The geologic inventory involves mapping in detail the three-dimensional distribution of materials in the overburden. The first step of this mapping is lithologic mapping. These data are then supplemented with other physical and chemical data that are of particular importance for reclamation. The basic unit by which these data are summarized is the "reclamation unit," which consists of a volume of sediment or rock, which possesses a unity of lithologic, physical, and chemical characteristics such that the material in it will respond in the same way when subjected to the same stress induced by a change in its physical or chemical environment. The work being conducted by the North Dakota Geological Survey is directed toward the identification and characterization of the "reclamation units" present in areas of proposed lignite mining in the state. The characteristics of a given "reclamation unit" are probably most strongly determined by the lithology (the type of material present). Where the material is near the surface, these inherent characteristics are modified by weathering and the transportation of weathering products either away from or into the material by groundwater.

The third concern in developing an inventory of the proposed mining area is the groundwater. Groundwater is of concern because of its importance as a supply of water in many areas and because it is complexly involved in the nature and quality of soils, the chemical characteristics of geologic materials, and in the stability of the surface form of the landscape. For these reasons, it is important to know the areas of groundwater recharge and discharge and the paths and rates of flow between them.

The fourth item in the premining inventory is, at the same time, the most important and the most difficult to obtain of all. It can probably never be attained completely. This is an understanding of the nature of the existing equilibrium in the landscape. Initially, this has the appearance of an academic concern, but deeper examination shows that it is far more than that. If, as we indicate above, the goals of reclamation can be met best by the construction of a landscape in equilibrium with its environment, then it is necessary to understand the relations which generate such an equilibrium in order to design a landscape which is stable. Since understanding is possible only through knowledge, and since there is no equilibrium landscape on earth about which more can be known than one that is about to be disrupted by strip mining, the best possible way to design an equilibrium landscape following mining is to thoroughly understand the existing landscape before it is disrupted. Only in this

way, can we develop the causal generalizations that relate the complex interactions of internal structure, permeability, and strength, surface form, climate, and hydrology.

Landscape Modeling

Once we have a complete inventory of existing conditions in an area of proposed mining, we can procede to the next step of landscape design, the construction of models of potential post-mining landscapes. In this phase of reclamation planning, the various materials available are examined to determine how they will respond to the different physical and chemical environments that will result from each of the landscapes being considered. The types of models that are used in this phase of planning range from simple, nearly intuitive, qualitative or semi-quantitative mental models to highly sophisticated digital computor models capable of handling large multicomponent arrays of interacting variables.

By analyzing the various components of alternative proposed landscapes, the morphology and stratigraphy that is most stable and best meets the requirements of alternative possible land uses will be determined. For example, if a certain surface morphology is constructed with a particular permeability distribution within the material, then the hydrological regime of the landscape is set. This hydrological regime will govern the amount of runoff and infiltration, the nature of stable soils, the mobilization and migration of soluable ions, along with a multitude of other factors. By changing either the morphology or the premeability distributions, the hydrological regime can be modified to a new equilibrium. The resultant equilibrium surfaces for a series of alternative designs can be evaluated, in this way, using the modeling approach to select the landscape that maximizes the three constraints of serving the intended use, being in stable equilibrium with the climate, and being economically feasible.

Through this procedure of landscape-design reclamation, the dual goals of reclamation, the return to agricultural productivity and the protection of water supply, can be best met. The first step in developing the capability to implement such an approach to reclamation is to develop an information base on existing conditions and the inter-action between them in landscapes that are about to be mined. The reclamation research project of the North Dakota Geological Survey is directed at developing a portion of this information base, and is the subject of the remainder of this paper.

GEOLOGY AND RECLAMATION

Geology of Lignite Occurrence

Potentially minable lignite occurs, in North Dakota, in the Sentinel Butte, Tongue River and Ludlow Formations of the Ft. Union Group. The lignite, which occurs in beds that range in thickness from a few millimetres to nearly 10 metres in places, is a minor constituent of these units, comprising less than 5% of the total thickness. About 60% to 80% of these formations consist of interbedded silt and clay that occurs in beds ranging from millimetres to ten's of metres in thickness. From 15% to

35% of these formations consists of silty, fine-grained to medium-grained sand in beds that range from 1 m to 30 m in thickness.

The glacial sediment that overlies the northeastern third of the region consists of pebble-loam (commonly called till), laminated silt and clay, and sand and gravel. The total thickness of these unconsolidated materials ranges from less than a metre to more than 100 metres in many places. The presence and thickness of glacial pebble-loam in the overburden of a proposed mining area is a very important factor influencing the physical and chemical characteristics of the overburden.

Figure 1 is a cross-section of part of the Tongue River Formation exposed in a cliff near Medora, North Dakota (3, 5). This section was completely exposed so the stratigraphic relations shown were actually observed, not inferred. Two very important observations can be made from this cross section. The first is that these rocks are complex. Different materials grade laterally into one another within fairly short distances. The same unit changes elevation markedly within short distances. The second, very important, observation that can be made from Figure 1, is that these rocks are simple. Although there is considerable change in lithology laterally, there is a rather simple repetitive sequence to the section. Lignite beds are generally continuous, and separate sequences of gray silt and clay, brown silt and clay, and sand. In short, the apparent complexity consists of the repetition of simple, coal-bounded cyclic-sequences.

A productive way to study these coal-bounded units is to determine the sedimentary environment in which they were formed, using the gross distribution of the various types of material and the small-scale sedimentary structures contained in the material. By relating the characteristics of these sediments to similar sediments that are being currently deposited, it is possible to develop a conceptual, depositional model that relates the various types of material to one another. Thus, the geometry of each body of sediment can be visualized and related to the other bodies of sediment found in the same environment. In approaching an unknown sequence of rock, the observed characteristics of the new rocks are compared with those of the various possible models. The model which seems best to fit the characteristics of the unknown rocks is then selected and used as a guide to interpret the three-dimensional relationships among the bodies of sediment within the area of interest.

This type of approach has been used successfully in North Dakota by Jacob and his associates (1, 3, 4, 5, 6, 7). They have studied both the Tongue River and Sentinel Butte Formations in considerable detail in several different small areas. Their findings are that the model that seems to fit these rocks in the areas studied is that of an alluvial flood plain. The sand beds and lenses represent channel fills or accretionary deposits formed by channel migration. The sandy silt to clayey silt beds that tend to weather to yellowish colors were deposited as natural levees along the channels. The gray clayey, silt, silty clay, and clay beds were deposited in the back-basin areas of the flood plain (3, 5).

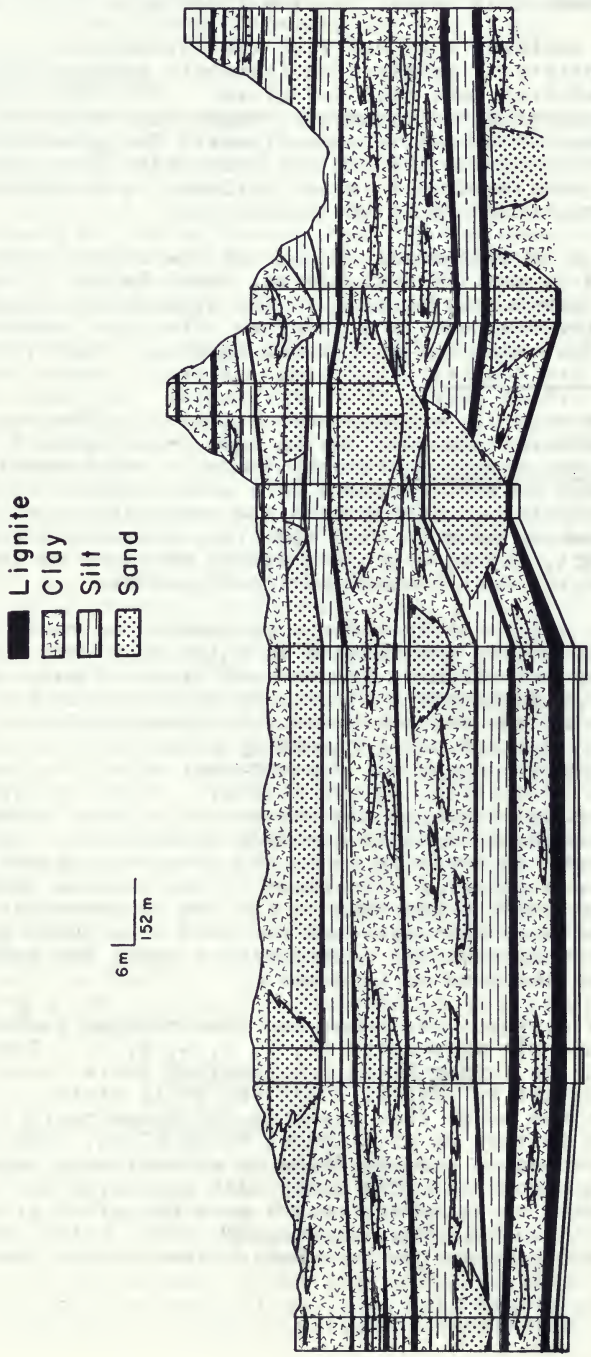

Fig 1: Cross section of Tongue River Formation at Medora, North Dakota (from Jacob, 1972)

This model has been successfully applied by NDGS personnel to study the overburden in areas of porposed mining.

The first step in the NDGS study was to collect stratigraphic data from three proposed mining areas. Samples were collected at intervals of five feet or less during the drilling testholes and core holes that were drilled by the operator to obtain data on the coal. Descriptive logs of these samples were combined with geophysical logs that included resistivity, spontaneous potential, natural gamma-ray, and gamma-gamma density to construct a final interpretive log of each site. These intrepretive logs were then combined into cross sections to depict the relations of the bodies of sediment in three dimensions. At this stage, the correlations were constantly being checked against the depositional models and modified to fit the most appropriate one. Using the cross-sections as a guide, contour maps of various important surfaces in the overburden have been constructed.

Samples collected from some of the testholes have been analyzed for a large suite of soluable ions as part of the Agricultural Experiment Station subproject. The data obtained include pH, electrical conductivity, Na^+, Ca^{++}, Mg^{++}, K^+, Cl^-, SO_4^{--}, HCO_3^-, CO_3^{--}, $CaCO_3$ equivalent, and SAR. The chemical composition of material is the result of a number of complex interactions. It is largely a function of the type of material. In general, glacial pebble-loam contains much less sodium, has a lower SAR and electrical conductivity, but generally has a higher lime carbonate content than do any of the bedrock materials. In general, the soluable-ion content of clayey sediment in the bedrock is greater than that of sandy material. This pattern is then modified by the various geochemical processes at and near the earth's surface. Ionic constituents are freed by weathering and transported by groundwater to produce geochemical patterns that reflect depth below surface and position in the groundwater-flow system.

SUMMARY

The focus of reclamation studies in North Dakota is on the development of a premining geochemical framework, which consists of physically and chemically defined "reclamation units," to serve as the basis for mine-plan design. The "reclamation units" are used to identify materials as deleterious or favorable for soil development and for the establishment of vegetation; they can then be placed at the surface of the reclaimed spoil or buried far from the surface depending on their characteristics.

The first step in development of "reclamation units" for a proposed mine area is the collection of geologic data on the overburden. Detailed descriptions of samples collected at 5-foot intervals from coal-exploration testholes are combined with geophysical logs to develop an interpretation of the geology at each hole. The materials are then correlated between testholes on the basis of established models of the environment of sedimentation of coal-bearing rocks. The resulting three-dimensional picture of the geology of the overburden forms the physical framework of the "reclamation units."

Samples collected from a portion of the testholes are

analyzed to determine the abundance and type of readily soluble ions. By and large, the chemical composition is directly related to the type of material. This pattern is modified to a greater or lesser degree by weathering, the position of material in the modern groundwater-flow system, or the position of material in a flow system that resulted from climatic or topographic conditions no longer in existence. The chemical data are integrated with the physical framework to develop the final "reclamation units."

Studies are also underway to develop the information base necessary to design the optimum landscape in reclaimed areas. The resulting landscape must assure a minimum of surface subsidence, slope instability, erosion by gullying, and contamination of groundwater and surface water with ions leached from the spoil material. The interactions of all the physical, chemical, and biological systems operating in a landscape make landscape design considerably more complex than it has been considered by many.

LITERATURE CITED

1. Chervin, V. B. High-and Low-sinuousity stream deposits of the Sentinel Butte Formation (Paleocene) McKenzie County, North Dakota. University of North Dakota, unpublished MSc Thesis, 73 p. Grand Forks, N.D., 1973.

2. Clayton, Lee, Moran, S. R., and Bickley, W. B., Jr., Stratigraphy, Origin, and Climatic Implications of Late Quaternary Upland Silt in North Dakota. North Dakota Geological Survey, Misc. Series, 54. 1975

3. Jacob, A. F., Depositional Environments of Parts of the Tongue River Formation, Western North Dakota. p. 43-62 in Ting, F.T.C. (ed) Depositional Environments of the Lignite-bearing Strata in Western North Dakota: North Dakota Geological Survey, Misc. Series, 50, 134 p. 1972.

4. Jacob, A. F. Elongate Concretions as Paleochannel Indicators, Tongue River Formation (Paleocene), North Dakota. Geol. Soc. America, Bull. v. 84, p. 2127-2132. 1973.

5. Jacob, A. F., Depositional Environments of Paleocene Tongue River Formation, Western North Dakota. American Assoc. Petrol. Geol., Bull. v. 57, no. 6, p. 1038-1052. 1973.

6. Jacob, A. F., Stratigraphy and Depositional Environments, Husky Lignite Mine, Dickinson, North Dakota (abs). North Dakota Acad. Sci., v. 28, p. 13. 1974.

7. Johnson, R. P., Depostional Environments of the Upper Part of the Sentinel Butte Formation, Southeastern McKenzie County, North Dakota. University of North Dakota, unpublished MSc Thesis, 63 p. Grand Forks, N. D. 1973.

8. Omodt, H. W., Schroer, F. W., and Patterson, D. D., The Properties of Important Agricultural Soils as Criteria for Mined Land Reclamation. North Dakota Agricultural Experiment Station, Bull. 492, 52 p. 1975.

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OTTER CREEK COAL RECLAMATION STUDY, MONTANA

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ABSTRACT

A tract of about 2,400 acres (971 hectares) of land near Ashland, Montana, underlain by strippable coal deposits, is being studied to describe potential hydrologic problems that may occur if the coal is mined and the land reclaimed. The purpose of the study is to provide the Bureau of Land Management with information to help evaluate and compare possible coal-lease areas. The ground-water resources are being evaluated with data from seven test holes drilled and cored by the U.S. Bureau of Reclamation. Additional data collected by the U.S. Geological Survey include geophysical logs, aquifer tests, information on existing wells, and chemical, spectrographic, and radiochemical analyses of water samples. A hydrologic monitoring program will document pre-mining conditions and provide guidance in solving potential problems associated with mining.

The 60-foot (18 metres) thick Knoblock coal bed and nine thinner coal beds in the Tongue River Member of the Fort Union Formation underlie the area. The Knoblock is a major part of the water-table aquifer in the area. A preliminary evaluation of available data indicates that shallow ground water moves west toward Otter Creek, but discharges into the Home and Threemile Creek drainages which are tributary to Otter Creek. In general, water flows from the drainage divides toward outcrops of clinker near the creeks.

Water wells tapping the Knoblock yield about 4 gallons per minute (0.3 litre per second); specific capacity is about 0.10 gallons per minute per foot of drawdown (0.021 litre per second per metre). Transmissivity of the major aquifer appears to be small; about 1 cubic foot per second (0.028 cubic metre per second) of water would be produced from a mine. Pumping water from mines would reduce ground-water flow toward streams.

Major water types from the coal are sodium bicarbonate, sodium sulfate, or sodium magnesium sulfate. Dissolved solids range from 1,210 to 4,090 milligrams per litre. The water produced from the mine would contain sodium in concentrations large enough to make it unsuitable for irrigating vegetation that might be used to stabilize the mine spoils.

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THE MOVEMENT AND OCCURRENCE OF SMALL MAMMALS ON A RECLAMATION PLOT

Steve A. McCann*

INTRODUCTION

When lands are laid bare by strip-mining, studies involving responses of animals to habitat changes become possible on a scale not often available to researchers. Thus, data gathering on eastern Montana small mammal distribution and habitats in strip-mined areas become feasible. Verts (13) and Yeager (15) have noted movements and ecology of small mammals in Illinois strip-mined areas. Yeager (15) recognized that invasion of strip-lands by mammals was related to the age of reclamation. In a study of the distribution of *Peromyscus maniculatus*, Verts (12) found that these animals preferred more recently mined areas. In Ohio, Riley (11) compared wildlife populations on strip-mined lands with those on various types of agricultural land. However, information on the relationship of mammals to reclamation in eastern Montana is lacking.

As part of an investigation to determine possible wildlife potential on strip-mined lands in Musselshell County of eastern Montana, an ecological study of small mammals was conducted. This study was initiated during the fall of 1970 and has continued to date. Distribution and population status of mammals as related to floral composition and topography were the aspects most intensively investigated.

DESCRIPTION OF THE AREA

The 12 acre research area is located in Musselshell County about 4.5 miles southeast of Roundup, Montana. Strip-mining operations began on this land in 1971. Six acres of overburden were removed and 39,000 tons of coal were tested for burning qualities. Spoil material was placed on two ridges encompassing six areas west of the pit (Figure 1). Topographic, soil and vegetative characteristics of this area have been previously described by Dusek and McCann (3; 4).

MATERIALS AND METHODS

Techniques used in small mammal censusing were as follows: 5 lines of 100 snap traps-placed 10 feet apart- were placed on the study area (Figure 1). Thus, each census line encompassed 1,000 linear feet. Traps were baited with rolled oats or a mixture of peanut butter and rolled oats. Census lines were operated for two consecutive nights and populations were calculated by Zippin's (16) method:

$$N = \frac{(Y_1)^2}{Y_1 - Y_2}$$

N= Total population
Y_1=First night's catch
Y_2=Second night's catch

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McCann(9) has shown little difference between this method and the standard three-night method of calculating populations within the study area.

Distribution and home ranges of small mammals were determined by placing Sherman live traps according to a grid pattern devised by McCann (10). Relative abundance of larger mammals were determined by observing sign (tracks, scats, cuttings, and dens) of individuals during summer and winter.

Nomenclature of mammals follows that of Hall and Kelson (5).

ACCOUNT OF SPECIES

Peromyscus maniculatus osgoodii

The only mammal which apparently invades stripped lands immediately after mining is the deer mouse. Dusek and McCann (3) indicated an increase of 2 mice per 1,000 linear feet in lines A and E which were adjacent to the mining site (Figure 1) over the normal population of 9 mice per 1,000 linear feet for 1971 (McCann; 9). This increase is perhaps due to some migration of deer mice from the mining area since the populations in line B, C, and D were completely eliminated due to mining. In 1972 a small number of adult male deer mice was trapped on lines B and D (Figure 1). No specimens were trapped at this time on line C (Dusek and McCann: 3). Benton, et. al. (1) reported that when Hurricane Agnes caused widespread flooding during 1972, small mammal populations were eliminated. *Peromyscus maniculatus* was the only mammalian species present in significant numbers four months after flooding. This appears to indicate that during reclamation's first stages, deer mice will immigrate into barren areas. During 1973 and 1974, deer mice inhabitated all census areas (Figure 2). During 1974, population numbers were as great or greater than those reported by McCann (9) for Musselshell County on all census lines.

McCann (10) has reported that deer mice inside the study area appear to occupy home ranges of 0.40 acres for females and 0.51 acres for males. In a ponderosa pine area in Colorado, Williams (14) reported that mature male deer mice has home ranges of 0.52 acres and mature female of 0.36 acres. His calculated home ranges were similiar to those of the test pit study area.

Microtus pennsylvanicus insperatus

During 1974, meadow voles were captured for the first time on all top-soiled areas of the study plot. Changes in physical conditions and habitat related to increased height of canopy of flora may be sufficient to initiate changes in mammal distribution (Verts, 13). Immigration of meadow voles into the study area maybe the result of this change. *Microtus* species prefer a canopy dense enough to formulate runways (Ingles, 7; Maser and Storm, 8). Blair (2) indicated that populations of meadow voles were much larger in areas of heavy than in those of sparse cover. Predation possibly plays a selective part in determining habitat preference. The periods of greatest small mammal activity occurs shortly after dawn and in the hours preceding dusk when vertebrate enemies are less active (Hamilton, 6). This sequence of activity plus vegetative canopy cover dense enough

for protection may provide meadow voles with a secure habitat.

McCann (10) has reported that meadow voles inside the study area appear to occupy home ranges of 0.13 acres for females and 0.23 acres for males. Blair (2) reported that meadow vole home ranges in a dry grassland community were 0.16 acres for females and 0.48 acres for males. This is compatible for calculated meadow vole home ranges in the study area.

Marmota flaviventris nosophora

The yellow-bellied marmot was observed in an active den during 1973 and 1974. Visual observations and tracks indicated concentrated use on areas supporting dense stands of yellow sweetclover. Very rocky areas appeared to be chosen by this animal for denning sites.

Eutamias minimus pallidus

The least chipmunk inhabits the ponderosa pine areas surrounding the study area. Several animals were observed during the summer of 1974. Top-soiled sites appeared to be the areas of heaviest usage.

Spermophilus richardsonii richardsonii

Colonies of Richardson's ground squirrels were located around the perimeter of the study area in 1973-74. These animals used primarily topsoiled areas.

Thomomys talpoides bullatus

Northern pocket gophers appeared in top-soiled areas in 1973. An indication of their presence is an earthern plugged mound. Activity was greatest in areas which provided suitable food and burrowing habitat.

Sylvilagus floridanus

Cottontails occurred throughout the area but were most abundant during the period of time immediately after mining. Visual sightings appeared to indicate that cottontails were utilizing large quantities of sweetclover (*Melilotus officinalis*), and when this species was not abundant, cottontail usage decreased. Verts (12) has noted that cottontail populations are not correlated with height and density of vegetation, but as indicated, some selection of vegetation may occur.

Lepus townsendii campanius

White-tailed jackrabbits were evident in the area during the winter of 1972-73. they appeared to utilize top-soiled areas more than other areas (Dusek and McCann; 3).

Canis latrans

Coyotes have been observed in the study area during all seasons. Similiarity between coyote and dog sign made study difficult, but tracks within the area were believed those of

coyote. These animals utilized top-soiled areas as hunting domains. Dusek and McCann (4) have indicated that cottontail rabbits and mice are a main source of food throughout the year. Thus, these animals may be utilizing test pit small mammal populations as a food source.

DISCUSSION

Small mammals found on reclaimed areas may be divided into four different groups: (1) Species becoming established as vegetational canopy becomes progressively dense; (2) Species distributed throughout the reclamation plot: (3) Species which invade reclamation soon after mining and are reduced in numbers as vegetation cover increases; and (4) Species whose distribution upon reclaimed areas is dependent upon special vegetational conditions.

In the first group, meadow voles appeared within the study area when vegetational canopy increased. Dusek and McCann (4) have indicated that when bare ground decreases to 11 percent of the canopy coverage, only meadow voles were trapped. When the percentage of bare ground increases from 11 percent, both deer mice and meadow voles were trapped together. Sites where only deer mice were trapped contained an average of 65 percent bare ground. Trapping sites within the study area which contained meadow voles, have decreased in the percent of bare ground from 100 percent to 22 percent (Dusek and McCann, 4). This decrease in small mammal succession occurring within the study area.

Mammals more or less uniformly distributed throughout the reclamation plot were cottontail rabbits, white-tailed jackrabbits, and coyotes. Most of these can be found upon a wide variety of habitats. Also, these animals will have a tendency to range over an area much larger than the reclamation plot.

The only mammal which apparently invades strip-mined areas directly after the mining process is the deer mouse. Other species may exhibit this same tendency, but the length of time of this study may not have been sufficient to record their activities.

Mammals limited in reclamation plot usage by special unknown factors are the yellow-bellied marmot, least chipmunk, Richardson's ground squirrel, and northern pocket gopher. Most were present only in specific areas and their limited distribution may be due to lack of cover, food, or both.

SUMMARY

Evidence of 9 species of small mammals were found upon a 12 acre reclamation plot in eastern Montana. The area was studied with emphasis being placed on factors which appear to enhance or limit distribution of various species. Thus, it appears that all physical and vegetational facets of the land should be considered when formulating a reclamation plan.

LITERATURE CITED

1. Benton, A. H. et. al. Recovery of a Small Population From Flooding Caused by Hurricane Agnes. Unpubl. report 1974 Soc. of Mammalogists Meet. 1974.

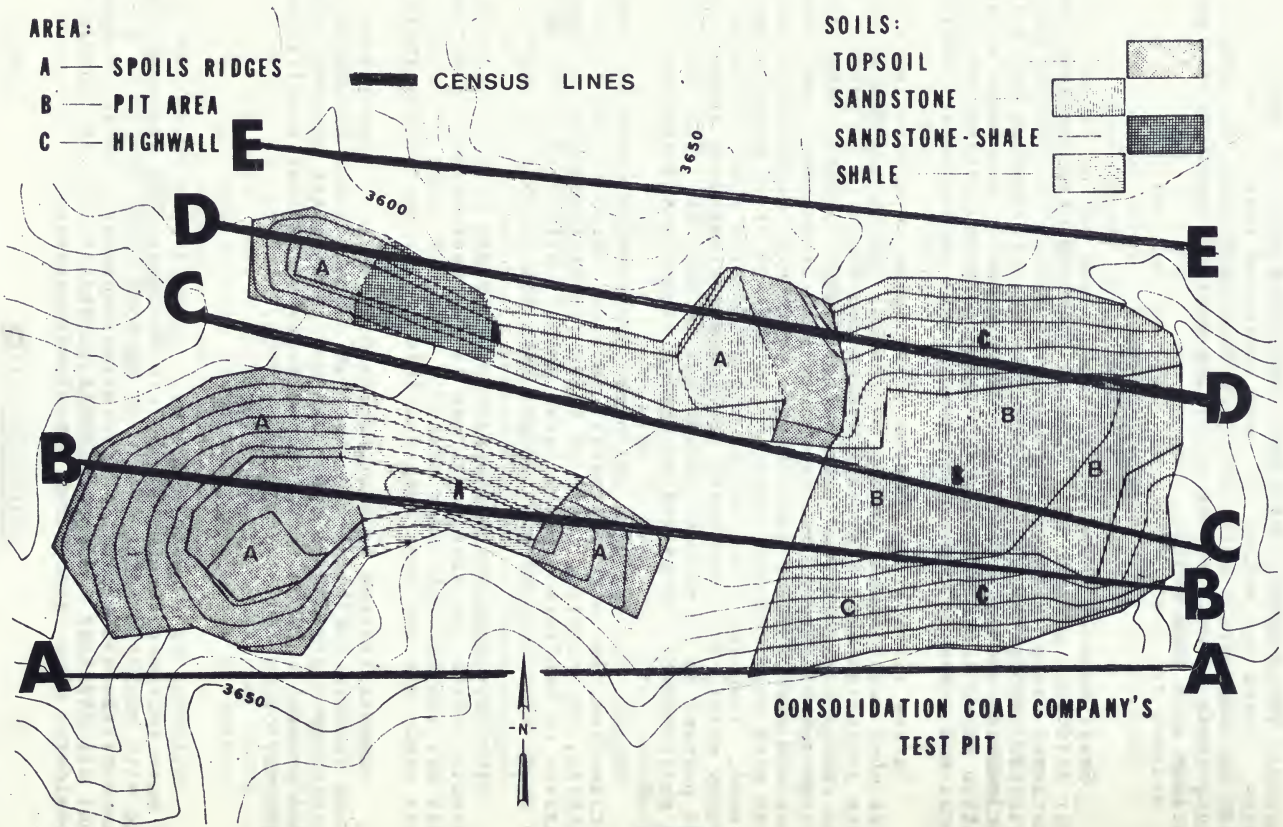
AREA:
A — SPOILS RIDGES
B — PIT AREA
C — HIGHWALL
CENSUS LINES
SOILS:
TOPSOIL
SANDSTONE
SANDSTONE-SHALE
SHALE
E
D
C
B
A
3650
3600
3650
A
B
C
-N-
CONSOLIDATION COAL COMPANY'S
TEST PIT

FIGURE 1.

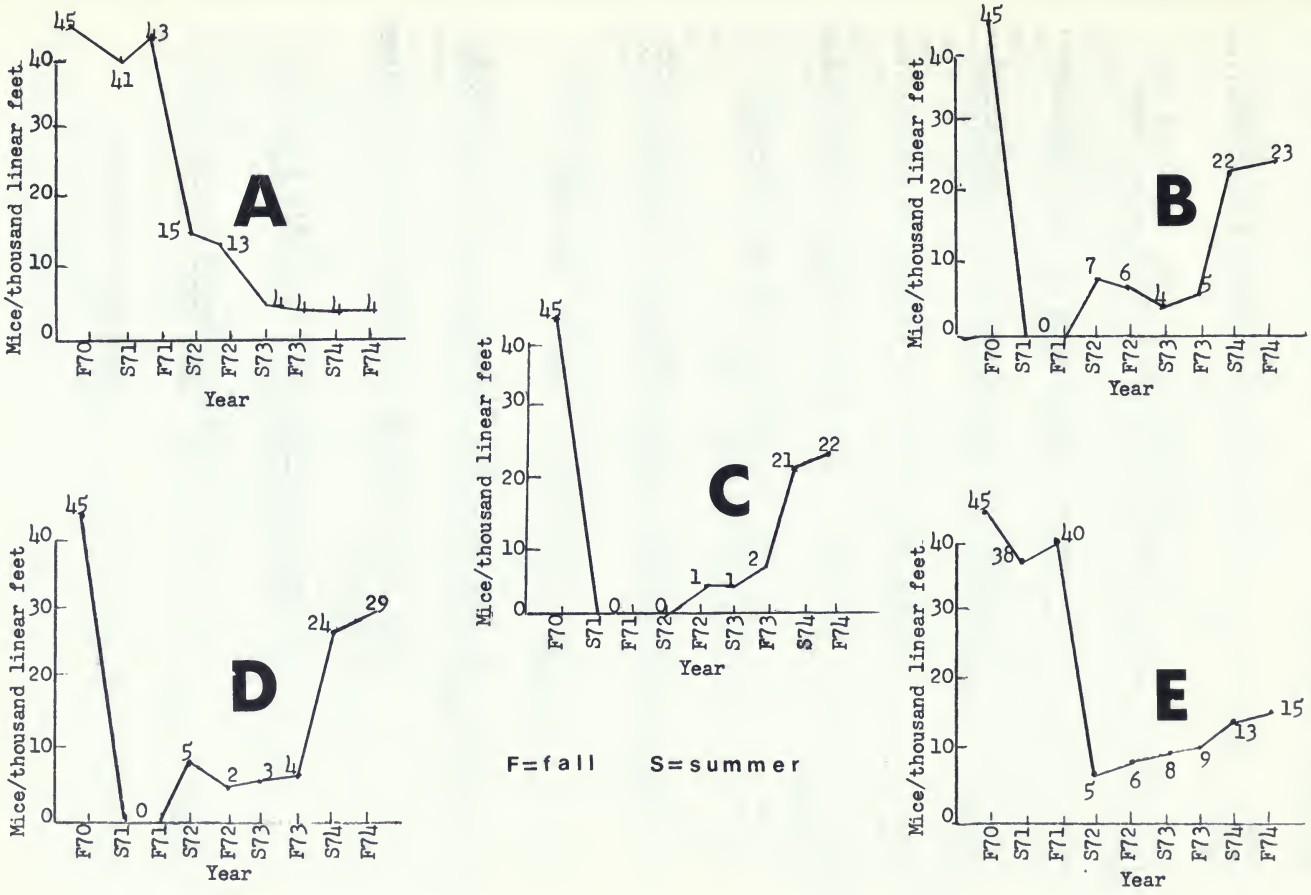

FIGURE 2. RECLAMATION PLOT DEER MOUSE CENSUS LINE POPULATION GRAPH

2. Blair, W. F. Home Ranges and Populations of the Meadow Vole in Southern Michigan. Jour. of Wildlife Mag. 4: 149-161. 1940.

3. Dusek, G. L. and S. A. McCann Bull Mountains Coal Field Study. Montana Department of Fish and Game and Consolidation Coal Co., Prog. Report I 53 p. 1973.

4. Dusek, G. L. Bull Mountains Coal Field Study. Montana Department of Fish and Game and Consolidation Coal Co. Prog. Report II 76 p. 1974.

5. Hall, E. R. and K. R. Kelson The Mammals of North America. Ronald Press Co., New York 1083 p. 1959.

6. Hamilton, W. J. Activity and Home Range of the Field Mouse *Microtus Pennsylvanicus Pennsylvanicu*. Ecology 18:255-263. 1937.

7. Ingles, L. G. Mammals of the Pacific States. Stanford Univ. Press. Stanford 506 p. 1967.

8. Maser, C. and R. M. Storm A Key to Microtinae of the Pacific Northwest. Oregon State Univ. Corvallis 162 p. 1970.

9. McCann, S. A. A Four Year Population Study of *Peromyscus Maniculatus* in Musselshell County, Montana. Proc. of the Mont. Acad. of Science 34: 14-20. 1974.

10. McCann, S. A. Home Ranges of the Meadow Vole and Deer Mouse on a Reclamation Test Pit in Eastern Montana. Montana Acad. of Science. 1975.

11. Riley, C. V. The Utilization of Reclaimed Coal Striplands for the Production of Wildlife. Trans. N. Amer. Wildlife Conf. 19:324-337. 1954.

12. Verts, B. J. The Population and Distribution of Two Species of *Peromyscus* on Some Illinois Strip-mined Land. Jour. Mamm. 38: 53-59. 1957.

13. Verts, B. J. Notes on the Ecology of Mammals of a Strip-mined Area in Southern Illinois. Trans. Illinois Acad. of Science 52: 134-139. 1959.

14. Williams, O. Home Ranges of *Peromyscus maniculatus rufinus* in a Colorado Ponderosa Pine Community. Jour. of Mamm. 36: 42-45. 1955.

15. Yeager, L. E. Coal-stripped Land as a Mammal Habitat With Special Reference to Fur Animals. Amer. Midl. Nat. 27: 613-635. 1942.

16. Zippin, C. The Removal Method of Population Estimation. Jour. Wildl. Mgt. 22: 325-339. 1958.

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EFFECTS OF SURFACE CONFIGURATION IN WATER POLLUTION CONTROL ON SEMIARID SURFACE MINED LANDS

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INTRODUCTION

The strippable coal deposits in the western states are located predominantly in arid areas of less than 14 inches of annual precipitation. Of the limited annual precipitation which reaches the soil surface, only minor amounts are stored in the soil. Over the ages, nature has developed drainage patterns which rapidly and efficiently shed all the free-standing surface water off an area leaving water only in the small depressions such as those formed by the burroughing of rodents and imprints left by grazing animals. Present mining procedures often times call for the duplication of such a pattern. The efficient drainage topography combined with soils of extremely low infiltration rates and the rapidly formed interconnecting pattern of rills and gullies results in the loss of significant amounts of water which could, if stored in the soil, have been utilized for plant growth. The generally smooth surfaced, recontoured terrain being left in the wake of strip mining, normally provides no depressions for impeding the flow of water but rapidly funnels sediment and nutrient laden excess runoff into the adjacent streams and gullies. During the winter months, snow is also blown off the smooth surfaces and deposited in nearby gullies and areas supporting stands of vegetation. One can visualize that large amounts of the critically needed water falling on smooth surfaced recontoured terrain are being completely lost to plant establishment and development.

COMPLETED SURFACE MANIPULATION STUDIES

In 1969 while R. L. Hodder was studying the effect of striking off the tops of abandoned mine spoils at the Rosebud Mine near Colstrip, he observed the lack of soil moisture within the steep sloped spoil piles. The observation and the need to retain water on the reshaped spoils lead to the birth of the first spoil surface manipulation studies at the Rosebud Mine.

The first precipitation trap basins were constructed by striking off ridge tops and gouging a series of large pits with a bulldozer blade to create an undulating surface on the flattened ridge of the spoils piles (Figure 1). Berms were constructed along the edges of the basins to prevent impounded water from flowing over the lower edges of the basin. The reconstructed ridge top and sides of the spoils pile were then fertilized and seeded with a diverse mixture of forb, legume, grass, and shrub seed.

By the following summer the basins supported dense stands

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of establishing vegetation. The precipitation trap basins had filled with water several times and caused the water to percolate into the spoils piles. Apparently, some of the water percolating down through the spoils influenced the amount of available soil moisture on the steep side slopes of the spoil piles as the once barren slopes established vegetation (Figure 2).

The encouraging results obtained from the first study lead to the subsequent design and development of new surface manipulation treatments and new implements to apply the treatments. The enactment of the Montana Strip Mining Law directed that the newly reshaped mine spoils must have slopes no steeper than 3:1 slope ratio. Consequently, all surface manipulation studies after 1969 were implemented on reshaped spoils with slopes of 3:1 or less.

During the following years, more encompassing studies were designed and implemented to evaluate several surface manipulation treatments.

The studies generally included applying the three surface manipulation treatments, gouging, dozer basins, and deep chiseling on sloping freshly shaped spoils.

The gouging treatment is accomplished with a specially designed implement (Figure 3). The basic machine consists of the hydraulically raised and lowered frame of a Grame Hoeme chisel plow. The chisels are removed and replaced with three, equally spaced, vertically positioned, heavy duty, 25 inch diameter, discs from an offset disc plow. As the surface manipulator is drawn forward with a tractor, the frame and discs of the implement are alternately raised and lowered thus forming elongated pits approximately 14-16 inches wide, 2-3 feet long and 6-8 inches deep. The gouges are applied on the approximate contour of the shaped spoils (Figure 4).

The dozer basins formed during 1970 and 1971 were constructed by alternately raising and lowering a bulldozer blade set on angle to create basins approximately 20-25 feet long, 25-30 feet from center to center, and 3-4 feet deep. Field experience with the method showed forming the basins with the front mounted bulldozer blade was a rather difficult and inefficient operation resulting in basins of varying size and characteristics. In 1972 a new implement was designed and constructed to improve the technique of forming large basins (Figure 5). The improved implement is mounted in place of a ripper tooth on the back of a D-9 bulldozer and is alternately lowered and raised with the bulldozers hydraulic system. The improved design forms a basin of similar size to that originally formed with the bulldozer blade. However, the new implement also includes a press bar for compacting the built-up edge of the basin and teeth extending from the bottom of the blade to form small grooves in the basin to collect and hold seed (Figure 4).

The deep chiseling treatment has been accomplished with a modified Graham Hoeme chisel plow with twelve chisels.

Surface manipulation treatments results reported by Hodder, Sindelar, Buchholz, and Ryerson, 1971 (1); Sindelar, Hodder and

Figure 1. Precipitation traps constructed on an old spoils ridge.

Figure 2. Broadcast seeding produced a dense stabilizing vegetative cover within one year.

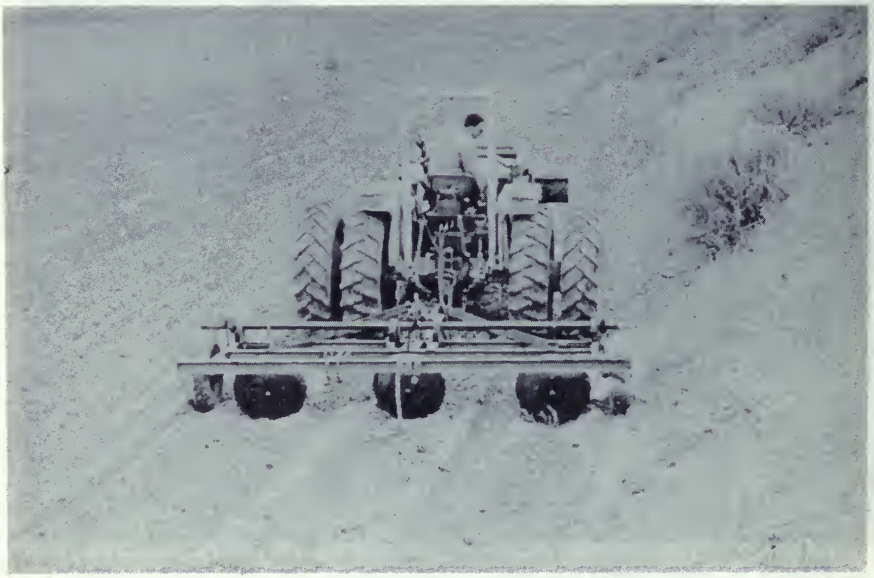

Figure 3. A prototype gouger operating on shaped spoils.

Figure 4. The dozer basin treatment shown toward the left of the photo as compared to the gouging treatment shown toward the right.

Majerus, 1972 (2); and Sindelar, Atkinson, Majerus and Proctor, 1973 (3), all report definite advantages in manipulating the surface of shaped spoils into configurations which limit runoff and encourage infiltration of precipitation. Studies conducted over several years show the gouging treatment stored more water in the upper four feet of soil, reduced moisture stress days significantly and resulted in better plant survival than did the other treatments (Figure 6). Table 1 shows the number of days during the 1972 growing season in which soil moisture dropped below the plant wilting point (15 atm.) at five levels for three treatments.

Table 1. Number of days during the 1972 growing season in which soil moisture dropped below the plant wilting point (15 atm.) at five levels for three treatments.

Treatment	0 ft	1 ft	2 ft	3 ft	4 ft
Chiseled	48	71	51	20	0
Dozer Basin	47	19	46	0	0
Gouged	46	6	0	0	0

Dozer basins reduced the number of moisture stress days at the one through three feet levels as compared to the chiseling treatment. Due to the lack of surface runoff and repeated presence of waterlines in the dozer basins, it is probable that precipitation trapped in the 3-4 ft deep basins penetrated deeply into the spoils (Figure 7).

The deep chiseling treatment did not improve soil moisture availability, but it did produce a good seedbed for seedling establishment.

Table 2 shows the plant density recorded for the three surface manipulation treatments in 1972 and 1973 and the percent plant survival during the sampling period.

The data show the percent plant survival for the gouged treatment during the 1972-73 sampling period was the greatest. Mean plant density was also greatest for the gouged treatment by the 1973 sampling period. The dozer basin treatment underwent a higher mortality rate (31 percent) during the sample period than the other two treatments but maintained greater plant density than did the chiseling treatment.

IMPLEMENTATION OF ADDITIONAL SURFACE MANIPULATION STUDIES

The combination of encouraging results and many unanswered questions led to the design of a large scale surface manipulation evaluation demonstration. The project now being implemented is sponsored by the Mine Drainage Pollution Control Branch

Figure 5. Dozer basins are now formed with a special designed implement.

Figure 6. Broadcast seeding of the gouging treatment area resulted in a good plant cover the second growing season.

Figure 7. Dozer basin depressions collect sediment laden runoff and establish dense stands of vegetation the first season.

Figure 8. Construction of surface manipulation treatment evaluation micro-watersheds at the Rosebud Mine Study Area (October 1974).

Table 2. Mean plant density per m^2 during 1972 and 1973 and percent survival rate of plants during the period for three surface manipulation treatments.

	Chiseled		Dozer Basin		Gouged	
	1972	1973	1972	1973	1972	1973
Grasses	108.8	42.0	148.4	47.0	96.6	51.0
Shrubs	9.6	4.0	25.6	8.0	19.2	10.0
Legumes	4.8	2.0	4.8	1.0	6.4	2.5
Total Density	123.2	48.0	179.2	56.0	132.2	63.5
Percent Survival 1972-1973	39%		31%		52%*	

* Significantly greater than other treatments at 0.10 level

of the Environmental Protection Agency located in Cincinnati, Ohio.

The project has been designed to evaluate the practicality and effectiveness of five surface manipulation treatments when applied to recently shaped strip mined coal spoils. Treatment effectiveness evaluations will include the following: efficiency of applying the treatments to large areas, vegetation establishment patterns, rates of surface runoff and erosion, quality of surface runoff, infiltration and percolation rates for water stored in surface depressions, chemical quality of water percolating through spoils, quantitative evaluation of the hydrologic cycle, changes in quantity and quality of existing water in underlying aquifers, and monitoring of underlying areas for potential new water aquifer development.

STUDY AREA SELECTION AND DESIGN

The three coal mining sites selected for the study are the Rosebud Mine near Colstrip, Montana; Knife River Coal Mine near Savage, Montana; and the Indianhead Mine near Beulah, North Dakota. The approximate acreages of the study areas are: Colstrip--75 acres; Savage--70 acres; and Beulah--55 acres. Each of the three study areas were located in areas of individually unique edaphic, topographic, and climatic characteristics. Specific sites were selected to enable maximum exclusion of confounding outside vectors such as excessive runoff, flooding and sedimentation. The types of drainage patterns, slope aspect, degree of slope, and uniformity of slope were all important considerations in final site selection. The contour of each drainage had to provide a bisecting drainage channel with opposing relatively uniform gradients and long slopes. The five treatments to be evaluated on shaped surface mined spoils are: gouging on topsoil, chiseling on topsoil, dozer basins on top-

soil, chiseling on spoils, and gougingon spoils. Chiseling on spoils will be considered the control against which all other treatments will be compared.

In order to accomplish the project objectives, two different types of treatment areas are necessary. The most extensive of the two types includes the application of each of the five treatments on large areas of two opposite exposures. More than 75 percent of each study area will be covered by this type of treatment.

Each large treatment area will provide: large contiguous areas for ground water recharge, extensive areas for the development of wind and water erosion patterns, comparison of opposite aspects, and opportunity to evaluate existing equipment for efficiency and suitability for large scale treatment application.

In order to achieve the project objectives a second type of treatment was used in conjunction with the extensive application type. The second type of treatment application consisted of constructing five microwatershed treatment areas near each other with provisions for accurate and intensive monitoring of the many factors.

DATA COLLECTION METHODS

A completely enclosed and insulated instrument protection building has been positioned at a central location within each of the study areas. The building is being used for housing all delicate data logging systems.

Within approximately 80 m of each instrument building a meteorological station has been installed. All the electrical output sensors are connected directly to the data acquisition system in the instrument shack by way of sensor wires extending through buried plastic pipe. Each meteorological data recording station consists of the following sensors:

1. Integrated wind speed
2. Wind direction
3. Direct solar radiation
4. Relative humidity
5. Precipitation (intensity and duration)
6. Barometric pressure
7. Evaporation potential (type A pan)
8. Air temperature at 2 meters
9. Air temperature at 1 meter
10. Soil temperature at four depths.

The heart of the data collection system is the data collection unit. The unit contains the circuitry to perform 32 channel switching, the analog to digital conversion formatting, data recording, and has a crystal controlled clock for time data.

All data collected and processed by the collection unit is stored on a two-track C-90 standard cassette tape. Data stored on the tape is played back into computer storage files on Montana State University campus. Computer programs will be developed for data compiling and analysis.

Water aquifer development, recharge, or discharge will be intensively monitored at each study area. Professional ground water hydrologists (Wayne Van Voast in Montana and Steve Moran in North Dakota) have been consulted in determining the final location and depths of at least twelve 4.0 inch inside diameter cased wells at each study area. Wells have been positioned and drilled so as to maximize the opportunity to monitor existing and developing water aquifer fluctuations, determine hydraulic gradients and flow direction and monitor possible changes in water quality. Water levels within three wells at each area will be monitored continuously with stage recorders. Water levels in the other wells will be measured weekly if major changes are developing and less frequently when changes are minor.

We are utilizing intermediate size lysimeters to determine water use patterns as a function of different surface manipulation treatments and to monitor the quality of soil water leaching through the soil. Recent lysimetery developments have made it possible to construct intermediate size units by employing fluid bag transducers with manometer readout.

Of the five lysimeters located at each research site, four have fluid bag transducers with manometer readout, and one has an electrical output transducer which will be connected to the data acquisition system.

Neutron access tubes will be randomly placed within all treatment areas. Moisture level readings will be collected weekly when major soil moisture changes are occuring and less frequently during the more stable periods.

MICROWATERSHEDS

Five microwatersheds, each encompassing 0.5 acre with approximate dimensions of 70 feet by 120 feet have been constructed at each study area (Figure 8). The upper end and two sides of each watershed are delineated with asphalt impregnated strips of chop strand fiberglass mat supported by rough sawn 2 inches by 4 inches lumber.

The lower boundary of each watershed consists of two runoff collection ditches each attached to the lower end of each side and extending to the lower middle thus forming a v-shaped runoff collection ditch.

At the lower edge of the microwatershed, at a point where the runoff collection ditches intersect, a concrete flume collection box is positioned so as to collect water from the ditches. A three inch Parshall measuring flume is bolted onto the lower end of the flume box.

Each stage recorder is fitted with a gear driven potentiometric output device which is connected directly to one of the data recording channels in the instrument building.

An automatic water sampler is positioned adjacent to and connected to the lower throat section of the Parshall flume. The cycle controlled sampler is capable of collecting up to 24 500 ml water samples at time intervals varying from five minutes

to two hours. The sampler is controlled with an adjustable interrupt switch mounted on the companion stage recorder. The switch will begin a water sample collection cycle when water flows through the Parshall flume.

LITERATURE CITED

1. Hodder, R. L., B. W. Sindelar, J. Buchholz, and D..E.. Ryerson. Coal Mine Land Reclamation Research. Mont. Agri. Exp. Sta. Res. Rep. 20, 45 p. 1971.

2. Sindelar, B. W., R. L. Hodder, and M. Majerus. Surface Mined Land Reclamation Research in Montana. Mont. Agri. Exp. Sta. Res. Rep. 40, 128 p. 1972.

3. Sindelar, B. W., R. Atkinson, M. Majerus, and K. Proctor. Surface Mined Land Reclamation Research at Colstrip, Montana. Mont. Agri. Exp. Sta. Res. Rep. 69, 106p. 1973.

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FACTORS RESTRICTING REVEGETATION OF STRIP-MINE SPOILS

J. F. Power, R. E. Ries, F. M. Sandoval, and W. O. Willis*

INTRODUCTION

Extensive deposits of lignite and sub-bituminous coal are located in the Sentinel Butte and Tongue River formation of the Fort Union geologic group in the Northern Great Plains states of North and South Dakota, Montana, and Wyoming. Within the past decade, strip-mining of these deposits has increased rapidly, and expansion of this activity is anticipated to continue at an accelerated rate (4). Several million acres of land within the Fort Union region may be subjected to mining activity.

Prior to 1970, only limited attention was devoted to attempts to revegetate areas disturbed by mining, probably because the area mined was too limited to be of economic consequence. Gwynn (3) was among the first to attempt revegetation of surface-mined areas. Unfortunately, most of the spoils available at that time resulted from relatively shallow mining and were not representative of the majority of spoils resulting from present-day operations.

To develop technology for reclamation, the Agricultural Research Service (United States Department of Agriculture) initiated research in 1970 to restore productivity to areas in the Fort Union region subjected to mining. Working through facilities of the Northern Great Plains Research Center at Mandan, North Dakota, a team of scientists was assigned to: (1) determine characteristic physical and chemical properties of spoils and overburden in the major coal fields in the Fort Union region; (2) evaluate the influence of these properties upon the growth potential of various plant species; and (3) develop reclamation methods whereby mined land can be restored to a level of productivity equal to or exceeding that existing prior to mining. These research activities have resulted in publications (5, 7) in which characteristic properties of spoils and overburden have been identified at several locations in the Fort Union region.

PROPERTIES OF SPOILS AND OVERBURDEN

Although properties of spoils vary widely throughout the Fort Union region, a number of generalizations can be made. For instance, spoils and overburden are characteristically near neutral to alkaline in pH, although frequently coal veins themselves are moderately acidic. Spoils commonly contain some soluble salts, with sulfates of calcium, magnesium, and sodium predominating. Most spoils also contain appreciable quantities of calcium carbonate. Normally, very few readily soluble chlorides, carbonates, or bicarbonates are present. Also, plant available forms

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of phosphorus are universally low in Fort Union spoils and overburden. Shales commonly contain appreciable exchangeable ammonium nitrogen, which is readily nitrified to nitrate nitrogen when exposed to weathering.

Variation existing in many of these generalized properties is characterized by the data given in Tables 1 and 2 on properties of overburden in the vicinity of Colstrip, Montana and Stanton, North Dakota, respectively. (All tables and figures are together at the end of this paper). Samples were collected by pneumatic drilling of unmined land. Vegetation consisted of native grasses (mainly *Agropyron* and *Stipa* species). As indicated by data on saturation percentage in Table 1, sandy colluvial deposits were found at Colstrip in the 25 feet of material above the upper coal vein. Between the first and second coal veins (31 to 52 feet), overburden was gray siltstone and shale. All overburden materials were moderately alkaline, with pH values in the 7.5 to 8.3 range. Lower pH values were usually found in the coal veins unless a high concentration of soluble sodium or magnesium sulfate was present. Appreciable quantities of calcium carbonate were found at all except surface depths.

Highest electrical conductivity at Colstrip was found in the sandy colluvial material below the root zone (5 to 25 feet). This distribution suggests that soluble salts have been leached from the root zone and were concentrated in the underlying sandy material resulting in a zone of maximum salinity beneath the normal depth of rooting (the maximum depth to which precipitation normally penetrates). Data in Table 1 indicate that magnesium sulfate was the primary salt accumulating at Colstrip, with lesser quantities of sodium and calcium sulfate present.

Other properties of concern include inorganic nitrogen status, sodium content, and cation ratios. At the Colstrip site, soluble sodium content at all depths was relatively low, particularly as compared to soluble calcium and magnesium contents. Consequently, sodium adsorption ratio (SAR) was generally low, indicating that no adverse physical conditions resulting from excess sodium should be encountered. However, soluble calcium to magnesium ratios are of concern because in agricultural soils the normal calcium to magnesium ratio is about 2 to 4 parts calcium to 1 part magnesium. In these overburdens, Ca/Mg ratios were generally in the 1/1 to 1/4 range. Consequently, sensitive species (clovers) may exhibit calcium deficiences when grown on these materials, even though the spoils contain about 10% free calcium carbonate. The data on inorganic nitrogen at Colstrip show little accumulation of nitrate nitrogen in the sandy profile. Exchangeable ammonium concentration was slightly greater in the heavier-textured lower strata. Typically, sandy materials contain little exchangeable ammonium because of their low cation exchange capacity. Nitrates present in the sandy material may have been leached from the root zone. In 1906, Buckman found considerable nitrate below the root zone of native prairie grasses at Forsyth, Montana (1).

The site near Stanton, North Dakota (Table 2) contrasts sharply with the Colstrip, Montana site in regard to texture of overburden (as indicated by percent saturation), and consequently in regard to other properties associated with texture. Below

the root zone, clay textures predominated at Stanton. Therefore, cation exchange capacity and exchangeable cation content would also be much greater. A notable difference between the two locations was in the ratios of the various soluble cations present. At Stanton, soluble sodium content was much higher relative to soluble calcium and magnesium, resulting in SAR values in excess of 13 at depths below the root zone. This fact, of course, indicates that spoils derived from shales at Stanton would have relatively poor physical properties when used for plant growth. Ca/Mg ratios of overburden at Stanton were higher than those at Colstrip, suggesting that magnesium-induced calcium deficiencies should be less of a problem at Stanton. Another parameter worthy of mention is the level of nitrate and ammonium nitrogen at Stanton. In the upper 23 feet, nitrate forms of nitrogen predominated, while below that depth, exchangeable ammonium nitrogen was prevalent. Depth at which nitrates no longer predominate corresponded to the maximum depth of annual temperature change (Figure 1), suggesting that 25 to 30 feet (8 to 10 meters) is the maximum depth of weathering in these materials. No viable nitrifying organisms were present below this depth, but were detected by plate counts made on samples from shallower depths (5).

Data in Tables 1 and 2 show the extent of variability found in overburden materials throughout the Fort Union region. The Colstrip site is generally sandy and relatively low in soluble sodium but high in soluble magnesium. In contrast, the Stanton site is high in clay and in soluble sodium content. In keeping with the geological character of the Fort Union region, higher clay content and higher sodium content are frequently encountered toward the eastern edge of the formation because this area was farthest from the source of sediment (Rocky Mountains) and was closer to a marine environment in the Paleocene era (6).

This range in properties between the Colstrip and Stanton sites results in contrasting types of problems in revegetating mine spoils. The remainder of this paper presents discussion on effects of these problems upon plant growth and will indicate how potentially adverse effects can be alleviated.

ALLEVIATING ADVERSE PROPERTIES OF SPOILS

Problems resulting from high exchangeable sodium can be corrected by replacing the exchangeable sodium on the clay surface with a divalent cation such as calcium. Common calcium salts present in spoils are calcium carbonate and calcium sulfate (gypsum). Solubility of calcium carbonate is too low to be of much value in replacing adsorbed sodium because the calcium content of a saturated solution of calcium carbonate at the pH values normally encountered is too low to exchange significantly with adsorbed sodium. Application of gypsum, a more soluble calcium salt, should result in some reduction in exchangeable sodium percentage. Layers of crystalline gypsum are sometimes encountered in overburdens and may aid in reclamation if thoroughly mixed with sodic layers. Data from several experiments in which gypsum was applied are presented in Figure 2, showing changes in SAR of gypsum-treated plots relative to that of untreated spoils as affected by time. This curve indicates that gypsum should result in up to a 40% reduction in SAR within a period of about 3 to 4 years. As a result, gypsum treat-

ment of spoils with an initial SAR greater than 12 to 15 would still have SAR values in excess of 8 or 10 in the upper 6 inches after treatment.

Calcium chloride is a more soluble form of calcium. Doering and Willis (2) have discussed the possible use of calcium chloride on spoils and they present calculations indicating that 10 to 30 tons per acre should effectively replace the exchangeable sodium (and reduce SAR) in an acre-foot of sodium-affected spoils. However, this practice is somewhat expensive (currently calcium chloride is about $150 per ton), requires sufficient levelling to permit application of leaching water, and requires significant quantities of leaching water to be effective. Consequently, this treatment may have limited utility.

Deficiencies of plant-available forms of nitrogen and phosphorus in spoils can be corrected by fertilization with these materials. Preliminary data on fertilization were presented by Sandoval et al. (7). Immobilization of phosphorus fertilizers into forms unavailable for plants does not appear serious (basically a calcium-phosphate system is involved). Consequently, it appears that several hundred pounds treble superphosphate per acre essentially eliminates phosphorus deficiences. A detailed experiment on phosphorus nutrition in spoils is presently in progress, utilizing radioactive phosphorus fertilizer to determine availability of phosphorus in topsoil, spoils, and fertilizers. Mineralizable forms of organic nitrogen are lacking in spoils (5). Once the original inorganic nitrogen supply is gone, annual nitrogen fertilization is required for adequate growth.

Mulches of various types are generally beneficial in establishing vegetation on spoils. However, organic mulches (straw, hay, residues) have a relatively short effect, decomposing within about a year. Inorganic mulches seem to be much more effective and longer lasting. A number of materials could be used as an inorganic mulch--including topsoil, gravel or sand, fly ash, and leonardite or oxidized lignite. Fly ash and oxidized lignite are frequently relatively high in soluble salts so would be of questionable value. Probably the least expensive and most readily available material would be soil material. A 2-inch mulch of topsoil has been used in a number of experiments, and its effects upon infiltration, runoff, and plant growth have been measured. Data are presented in Figure 3 showing how 2 inches of topsoil increased infiltration. Without topsoil, infiltration essentially stopped after 1 hour. With topsoil, infiltration was not only greater during the 1st hour, but continued to increase during the 2nd hour. These tests were made on spoils having an SAR value of about 25, which were levelled and seeded to grass in 1970 (without topsoil, essentially no grass stand survived).

No replicated experiment conducted by the ARS staff at Mandan has been in progress sufficiently long to permit making definite conclusions regarding the level of productivity resulting from applying various treatments to spoils. To date, dry matter production of perennial grasses seeded on spoils have been measured eight times for treatments involving either gypsum or 2 inches of topsoil. These eight measurements of yield were

obtained from several different experiments during the years 1972, 1973, and 1974. Average dry matter yield for these eight experiment-years is given in Table 3. These data are presented by treatment (check, gypsum, and topsoil), and by SAR of the spoil materials. In all instances, plots were adequately fertilized. Grass species were primarily pure stands of crested wheatgrass (*Agropyron desertorum*), or a mixture of cool-season grasses, mainly western wheatgrass (*Agropyron smithii*), green needlegrass (*Stipa viridula*), and slender wheatgrass (*Agropyron trachycaulum*). A few warm-season grasses were usually seeded in these mixtures (mainly sideoats grama and little bluestem), but they seldom survived.

In highly sodic spoils without topsoil treatment, grass seedings were essentially a failure, even with gypsum treatment. With 2 inches of topsoil, such spoils yielded up to a few thousand pounds dry matter per acre. On spoils lower in sodium, several thousand pounds dry matter per acre were produced without treatment other than fertilization. Gypsum increased dry matter production on moderately sodic spoils somewhat, but over 4000 pounds of dry matter per acre was produced with 2 inches of topsoil (Table 3). For comparison, dry matter yields are given in this table for the 1972-1974 period for native mixed prairie, without and with adequate nitrogen fertilization, produced on undisturbed Grail silt loam at Mandan, North Dakota. Grass yields on spoils frequently equalled or exceeded those obtained from unfertilized grass on undisturbed soil, but were less than those obtained for adequately fertilized grass on unmined soil. Judgement cannot yet be made on longevity of stand on mined lands. In no experiment in which over 2 inches of topsoil has been applied has more than 2 years of data been collected. Consequently, it is premature to draw any final conclusions from these experiments at this time.

In the preceding discussion, some generalizations have been made regarding properties of spoils and overburden in the Fort Union region, and some of these properties have been related to plant growth. The third objective of this research program--to develop methodology whereby adverse effects of growth-restricting properties are alleviated--has been discussed briefly. Although a number of research projects directed toward this objective are in progress, none has existed long enough to provide definitive solutions to these problems. In most instances, results are being evaluated with perennial vegetation, which requires a minimum of 5 years of growth in semiarid climates before even tentative conclusions can be drawn.

Objectives of some of these experiments on this topic which are in progress include: (1) to determine depth of topsoil and subsoil required for replacement over spoils varying in sodium content to provide different levels of production of several forage and grain crops; (2) to evaluate effects of date of planting and added water on germination, emergence, survival, and succession of various grass species mixtures planted on spoils; (3) to determine plant growth potential of overburden materials varying in physical and chemical properties as typified by overburden materials collected from different depths; (4) to evaluate effects of several different salt solutions upon germination, emergence, survival, and production of a number

of different perennial species contrasting widely in salt tolerances; and (5) several experiments in which a number of combinations of the factors discussed above are factorially combined. When results of these experiments become available, greatly improved methodology can be developed by which plant growth-restricting properties of Fort Union spoils can be overcome.

ACKNOWLEDGEMENT

The authors wish to acknowledge the support of the U.S. Forest Service Surface Environment and Mining (SEAM) program in promoting and partially financing this work. Also, appreciation is expressed to the several coal and power generating companies and cooperatives who actively cooperated in this work, frequently expending thousands of dollars in earth-moving activities. U.S. Soil Conservation Service has provided technical assistance and plant materials for several of these experiments. Also, the authors wish to thank the support staff of the North Great Plains Research Center for their efforts on these projects.

LITERATURE CITED

1. Buckman, H. O. Moisture and Nitrate Relations in Dryland Agriculture. Proc. Amer. Soc. Agron. 2:121-138. 1910.

2. Doering, E. J. and W. O. Willis. Chemical Reclamation of Sodic Strip-mine Spoils. ARS-NC-20, USDA-ARS, Peoria, Illinois. 8 p. 1975.

3. Gwynn, Thomas A. Rehabilitation of Lignite Areas of North Dakota Following Surface Mining. Knife River Coal Company, Bismarck, N. Dak. 15 p. 1965.

4. North Central Power Study. Report of Phase I. Prepared by Cordinating Committee, North Central Power Study. U.S. Bureau of Reclamation, Billings, Mont. 1971.

5. Power, J. F., J. J. Bond, F. M. Sandoval, and W. O. Willis. Nitrification in Paleocene Shales. Science 183:1077-1079. 1974.

6. Royse, C. F., Jr. A Sedimentologic Analysis of the Tongue River-Sentinel Butte Interval (Paleocene) in the Williston Basin, Western North Dakota. Sedimentary Geology 4:19-80. 1970.

7. Sandoval, F. M., J. J. Bond, J. F. Power, and W. O. Willis. Lignite Spoils in the Northern Great Plains--Characteristics and Potential for Reclamation. Proc. 1973 Research and Applied Tech. Symp. on Mined-Land Reclamation. Pittsburgh, Penn. pp. 117-133. 1973.

Table 1. Properties of overburden at Site B-1, Big Sky Mine, Colstrip, Montana.

Depth	pH	$CaCO_3$ equiv.	Saturation	Elect. cond.	Saturation extract					Exch. NH_4	NO_3
					Ca	Mg	Na	SO_4	SAR[1]		
ft.		%	%	mmhos/cm	meq/l					ppm	ppm
0-1	7.5	1	27	.3	3	2	< 1	< 1	.2	2	2
1-3.5	8.2	11	34	.5	1	2	< 1	< 1	.4	1	2
3.5-5	8.3	11	29	.5	1	2	2	< 1	1.5	1	3
5-15	7.9	10	23	6.7	19	48	24	88	4.2	1	3
15-20	8.1	12	30	9.7	26	100	41	161	5.2	1	4
20-25	7.8	12	25	6.1	25	52	19	91	3.0	1	3
25-31[2]	7.0	11	-	2.1	11	13	6	24	1.6	2	3
31-34	7.5	2	57	1.5	7	9	4	17	1.6	9	3
34-40	7.8	5	28	1.2	6	6	2	11	.9	2	3
40-46	7.8	22	40	1.0	3	4	2	6	1.2	3	4
46-52	7.0	14	50	1.6	7	8	5	14	1.9	4	3
52-60[2]	6.6	6	-	1.6	7	7	7	12	2.5	5	4

[1] Sodium adsorption ratio

[2] Coal

Table 2. Properties of overburden at Site No. 2, Glenharold Mine, Stanton, North Dakota.

Depth	pH	$CaCO_3$ equiv.	Saturation	Elect. cond.	Saturation extract				Exch.	
					Ca	Mg	Na	SAR[1]	NH_4	NO_3
ft.		%	%	mmhos/cm	- - - - - meq/l - - - - -				ppm	ppm
0-3	7.0	2	50	2	-	-	-	2	1	1
3-10	8.2	15	128	8	17	26	62	13	3	6
10-18	8.0	7	181	5	8	10	40	14	2	34
18-23[2]	4.5	3	-	9	23	24	73	15	5	37
23-50	7.7	11	142	3	1	1	31	31	10	2
50-60[2]	6.9	8	-	5	4	3	54	30	16	3
60-96	8.1	13	164	2	1	1	30	30	15	2
96-104[2]	7.0	11	-	2	1	1	22	22	16	2

[1] Sodium adsorption ratio

[2] Coal

Table 3. Average dry matter production for perennial grasses grown on strip-mine spoils, 1972-1974.

Treatment	High SAR[1/]	Moderate SAR[1/]	Average all tests
Check	70 (5)	3330 (3)	1290 (8)
2" topsoil	1550 (5)	4270 (3)	2570 (8)
Check	100 (3)	3330 (3)	1770 (6)
Gypsum	380 (3)	3730 (3)	2060 (6)
Gypsum + 2" topsoil	1220 (3)	4270 (3)	2720 (6)

Yield of native prairie on Grail silt loam at Mandan, 1972-1974 = 1330 lb/acre without fertilizer, 4640 lb/acre with fertilizer.

1/ High SAR spoils have SAR values over 15, moderate SAR spoils have SAR values less than 15.

2/ ( ) = number of experiment-years included in mean.

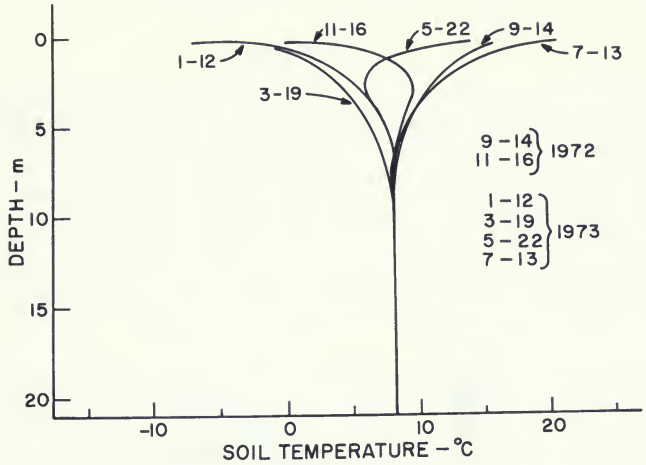

Figure 1. Soil temperature as a function of depth measured at bimonthly intervals at Stanton, North Dakota.

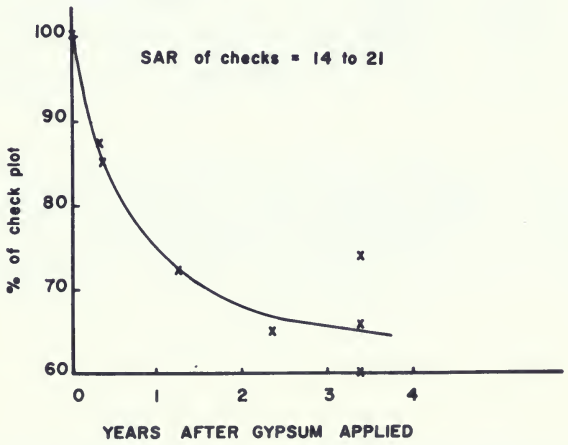

Figure 2. Effect of time on change in sodium adsorption ratio (SAR) in upper 6 inches of spoils resulting from gypsum treatment.

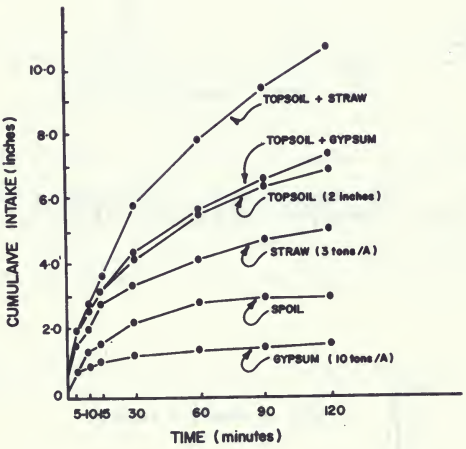

Figure 3. Effect of 1970 surface treatment of mine spoils upon cumulative infiltration in tests made in 1974.

* * *

WATER IN THE MADISON GROUP, POWDER RIVER BASIN, WYOMING AND MONTANA

W. R. Miller, W. G. Hodson, F. N. Visher, and F. A. Swenson*

ABSTRACT

The Madison Group aquifer (limestones and associated rocks) of Montana and Wyoming may furnish supplemental industrial water supplies for the coal-rich Powder River basin. The potentiometric head in the Madison ranges from about 1,000 feet (300 metres) below land surface in the south and south-central parts of the basin to 1,000 feet (300 metres) above land surface along the major streams in the north part of the basin. Water movement is generally away from the outcrop areas in the mountains into the basin, then northward. In the southeastern part of the basin, movement is to the southeast around the south end of the Black Hills.

The depth to the top of the Madison ranges from land surface in the mountains surrounding the basin to nearly 16,000 feet (4,900 metres) below land surface along the axis of the basin. The thickness ranges from 200 feet (60 metres) at the south end of the basin to 1,400 feet (430 metres) at the north end.

Well depths range from about 500 feet (150 metres) in the outcrop areas to 10,040 feet (3,060 metres) near Midwest, Wyo. Most of the wells more than 5,000 feet (1,500 metres) deep are for industrial use. The deepest public-supply well is less than 3,200 feet (980 metres) deep.

The largest measured yield from the Madison was 7,200 gallongs per minute (450 litres per second) from a well 4,975 feet (1,516 metres) deep near Midwest, Wyo. A public-supply well near Newcastle, Wyo., yielded 1,500 gallons per minute (95 litres per second) and an industrial well at Bell Creek, Mont., yielded 1,300 gallons per minute (82 litres per second). In several places in the basin, well yields were less than 50 gallons per minute (3.2 litres per second).

The dissolved-solids concentration of water in the Madison Group ranges from 140 milligrams per litre in the outcrop areas to 5,900 milligrams per litre at the northeast end of the basin. No data are available from the center of the basin. Near Midwest, Wyo., the dissolved-solids concentration of water from the Madison was 2,640 milligrams per litre. Water from the Madison near Bell Creek, Mont., contained less than 1,000 milligrams per litre.

* * *

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GROUND WATER IN COAL STRIP-MINE SPOILS, POWDER RIVER BASIN

Perry H. Rahn*

SUMMARY

Large quantities of strip-mine waste will ultimately be replaced in mined out areas in the Powder River Basin, Wyoming and Montana. This study concerns the hydrologic characteristics of the waste, and the chemistry of the water which occurs in the spoils.

Preliminary observations indicate that the porosity of stripped overburden increases when it is dumped as spoils. The permeability of the spoils varies greatly from mine to mine and depends in part on the local stratigraphy. Permeability is low where the overburden is shale with interbedded sandstone, such as at the Decker, Montana, or at the Dave Johnston Mine at Glenrock, Wyoming. Permeability is high where the overburden is mostly alluvium, such as at the Wyodak and Belle Ayr mines at Gillette and at the Big Horn Mine at Seridan, Wyoming.

The permeability of the spoils also depends on the mechanical equipment used in removing and transporting the overburden. Dragline-dumped spoils are looser and have greater permeability than scraper-dumped spoils, presumably due to the compaction by the heavy scraper tires. This suggests that if a permeable spoils deposit is a desired end product of strip-mining, then dragline excavation is preferable to scraper excavation.

Twenty-one water samples collected from local shallow ground water and from old spoils areas were analyzed for chemical constituents. All samples had greater than 250 ppm sulfate, the upper drinking water limit recommended by the U.S. Public Health Service. The samples were also high in calcium, magnesium, and total dissolved solids.

Water table levels indicate that the spoils at the Wyodak, Belle Ayr, Big Horn, and Decker mines will become saturated to varying degrees upon abandonment. Where these spoils are permeable, they will become man-made aquifers--an inadvertent beneficial end-product of strip mining.

INTRODUCTION

The hydrogeology of dumps of stripped overburden and waste from coal strip mines is being studied in the Powder River Basin, Wyoming and Montana. Primary emphasis of this research is to determine the hydrologic environment and characteristics of these spoils that are placed back in the strip-mined areas.

This research began in July, 1974, and will continue until July, 1976. This paper presents some preliminary results of the research.

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Acknowledgement is extended to the Old West Regional Commission for the financial support of this research.

GEOLOGY

The Powder River Basin is a broad intermontane basin about 250 miles along and 100 miles wide, bounded by the Black Hills to the east and the Bighorn Mountains to the west. Structurally, the basin is a broad asymmetric syncline which drops Paleozoic rocks as much as 12,000 feet below sea level.

The Powder River Basin contains rocks ranging from Paleozoic to Holocene in age. Major coal beds are found near the top of the Paleocene Fort Union Formation, just below the Eocene Wasatch Formation. Both of these Formations are continental deposits of semi-consolidated sandstone and shale. Cenozoic erosion has exposed coal beds in a belt from north of Glenrock, Wyoming, through Gillette, Wyoming, to Colstrip, Montana. During Holocene time the coal beds locally have been burned several hundred feet into the hillsides at most outcrops, forming a brick-red rubble called "clinker". Those outcrops of coal under flood plains are generally not burned and form some of the most valuable economic deposits of coal.

GROUND WATER

Recharge to the Fort Union and Wasatch formations is by local precipitation, which averages about 15 inches per year in the Powder River Basin.

Ground water conditions at the existing coal strip mines can vary considerably. Figure 1 shows that the water table is above the coal bed being mined at the Wyodak Mine at Gillette, Wyoming. (Note: All tables and figures are given together at the end of this paper.) The water table is high here because the mine is under the flood plain of Donkey Creek. In fact, the probable reason for the existence of such a thick coal with only a small amount of overburden is because the coal has been saturated during Holocene time and thus the prairie fires were unable to burn the coal at this point. Upon abandonment, ground and surface water will fill in the pit at the Wyodak Mine to near the level of the present water table shown on Figure 1. Thus the pit will become a lake since the amount of spoil piles are small (unless future mining continues at great length into the westerly hillside where the overburden becomes greater).

Figure 2 is a sketch of the Dave Johnston Mine near Glenrock, Wyoming. In contrast to Wyodak, the water table at the Dave Johnston mine is below the pit. No ground water seeps are present and no pumps are needed. Upon abandonment this mine will remain dry. No lake will be created; the spoils will not become saturated.

Most of the coal strip mines in the Powder River Basin have ground water conditions somewhere between the two extremes illustrated above. For instance the spoils at the Decker Mine, Montana (Figure 3) will become saturated to a large degree after abandonment, as will the spoils at the Belle Ayr Mine, Bighorn, Colstrip, and most of the other coal mines in the Powder River Basin.

The increase in volume from original overburden to spoils is reportedly about 1.3X. Where the spoils will become saturated, the possibility arises that the spoils could become a man-made aquifer. Where a sufficient storage volume of saturated spoils is created and the permeability is large, this artificial aquifer will be a beneficial--albeit inadvertent--side-effect of strip mining.

FIELD PERMEABILITY MEASUREMENTS

Field permeability measurements are being conducted in the spoils areas. Future research will involve pump tests where saturated spoils occur. Present data is limited to field infiltration and laboratory tests, which are useful to show relative values of permeability.

Figure 4 shows five ring infiltrometers in use on a spoil pile at the Bighorn Mine north of Sheridan, Wyoming, The rate at which water percolates from the cylinder into the soil is determined. Figure 5 shows the results of the infiltration from a test site on spoils near Acme, Wyoming. The sandy alluvial spoils here are quite permeable but have a wide range in infiltration rates, from 23.0 inches/hour to 0.2 inches/hour. They average 8.1 inches/hour.

Where the spoils consist mostly of shale and clay, such as the spoils east of the Bighorn Mine north of Sheridan, the infiltration rate averaged only 0.5 inches/hour.

Field infiltration measurements also show the effect of compaction on the permeability of the spoils. In Figure 5, cylinders 1 to 4 were in relatively unconsolidated spoils whereas cylinder 5 was in a compacted roadbed. Where scrapers have dumped the spoils and the heavy tires have compacted the spoils, the infiltration may be one to two orders of magnitude less than dragline-dumped spoils. This suggests that draglines are a better method of removing and emplacing spoils if a more permeable deposit is a desirable end-product of strip mining.

LABORATORY PREMEABILITY MEASUREMENTS

Utilizing a constant head permeameter (Figure 6), disturbed samples from spoils dumps in coal strip mines in the Powder River Basin were tested in the laboratory at the South Dakota School of Mines and Technology. The objectives of the tests were (1) to determine permeability of the samples and (2) to try to establish a relationship between permeability and packing of the samples.

Different methods of packing the soils into a six-inch diameter test cylinder were conducted in order to obtain the best method for packing the disturbed spoils samples. Methods used include (1) a rotamp machine, (2) hand tamp with a blunt rod, and (3) dropping the test cylinder one inch. Using a fine-medium grained sand as a trial medium, the results of these three methods indicated that the best correlation was obtained by dropping the permeameter from a height of one inch a varying number of times for every 3 1/2 inch thickness of sample deposited in the cylinder. The permeameter was run for one hour

following the commencement of dripping from the permeameter spout, thus ensuring the complete saturation of the sample. Each sample was run four times at varying degrees of cylinder-drop compaction. Each of the four runs includes four measurements of discharge.

As shown by Figure 7, there is a relationship between the permeability of the spoils and the packing. The exact relationship is difficult to ascertain due to the large number of variables--e.g., varying amounts of clays vs. varying amounts of coarse-grained materials in each sample. However, in a general sense, permeability decreases with increasing density. This conclusion supports the field infiltration determination described above. Additional tests will be made to determine the effects of different types of spoils materials on permeability and porosity.

WATER QUALITY

Ground water is being collected and analyzed for chemical quality by the South Dakota School of Mines and Technology Engineering and Mining Experiment Station. Samples are being collected from local shallow domestic and stock wells and from ponds and wells in spoil piles.

Table 1 shows the data from 20 water samples collected during the past year. Also shown are the U.S. Public Health Service recommended drinking water limits. From Table 1 the following observations can be made:

(1) All 20 samples contain greater than 250 ppm sulfate, the recommended drinking water limit.

(2) Almost all samples have high calcium, magnesium, and TDS.

(3) Manganese is very high in two samples from a well and spoil seep at the Wyodak Mine.

(4) Sodium is very high in two samples from the Decker Mine.

(5) Nitrate is high in one sample from the Decker Mine. This is probably due to the explosives used in blasting.

(6) Trace elements analyzed in two samples, one sample from a spoil seep at the Bighorn Mine and one sample from a ground water seep in the Decker Mine, show that cadmium is the only trace element above recommended limits.

A statistical "t" test was used to determine if there is a significant difference between natural (background) ground water quality and the quality of ground water in spoils. It logically would be expected that the spoil water would contain more dissolved minerals because the sediments have been broken up, allowing for new contacts of minerals with percolating water. However, our data does not strongly support this conclustion. Using samples OW-3, 4, 5, 6, 7, 11, 18, and 19 as background ground water and OW-2, 8, 9, 10, 12, 13, 15, and 17 as spoils water, it can be shown that--at a five percent level of significance--the TDS, magnesium, and sulfate of spoils water is slightly higher

(about 60 percent higher) than background ground water; but there is no difference between calcium, sodium, and manganese

CONCLUSION

This investigation is not completed, but some tentative conclusions can be made at this point.

It appears that inadvertent aquifers will be made where spoils from coal strip mines become saturated after abandonment. The permeability of these deposits is large where the overburden is sandstone or alluvium and small where the overburden is shale. In addition, dragline-dumped spoils have greater permeability than scraper-dumped spoils.

Data on water quality does not indicate that ground water in spoils is much worse than the existing ground water in the shallow aquifers near the coal mine.

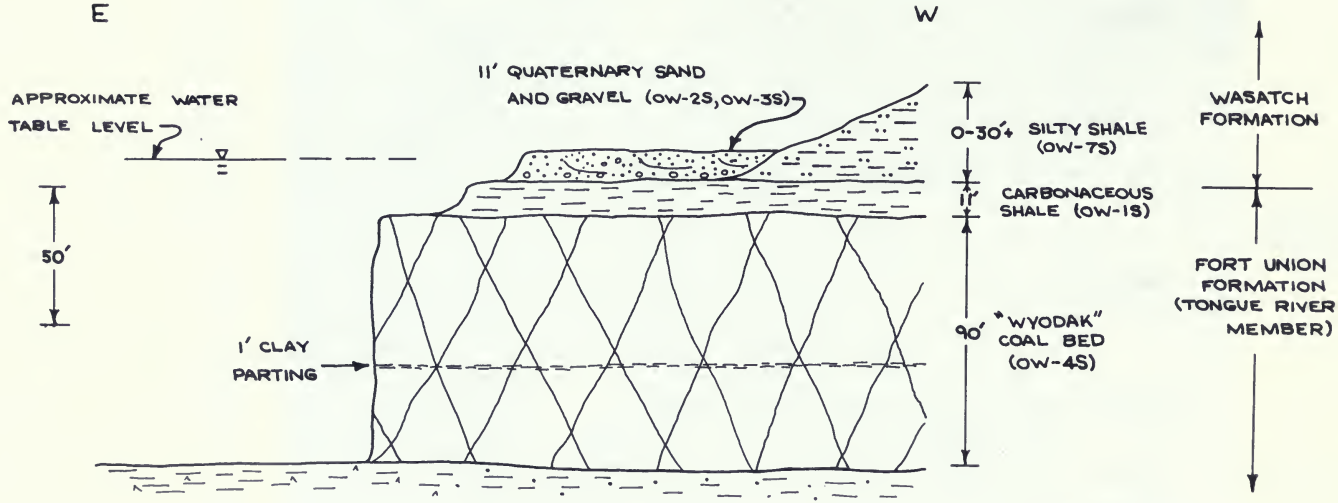


Fig. 1. Cross-sectional sketch of the south pit at the Wyodak Mine, Gillette, Wyoming.

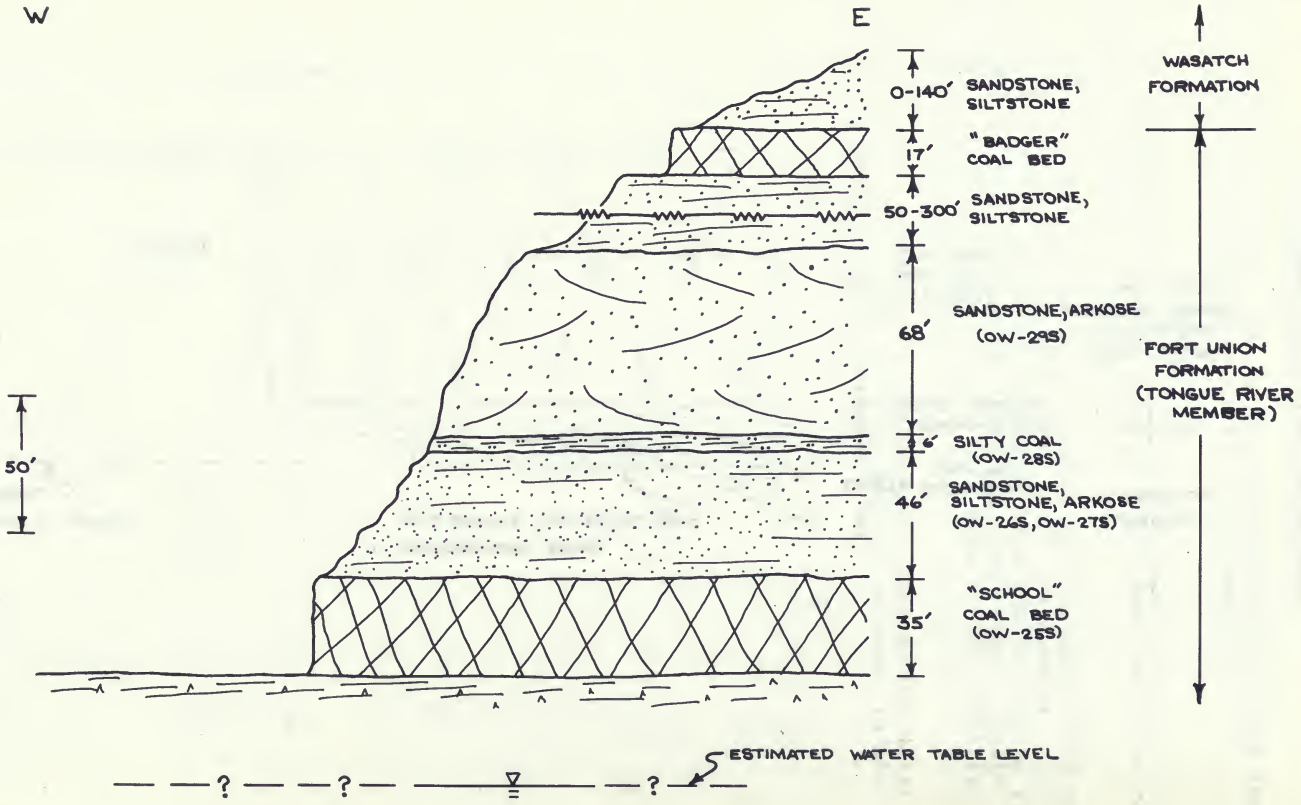


Fig. 2. Cross-sectional sketch of the Dave Johnston Mine north of Glenrock, Wyoming.

Fig. 3. Working face of the Decker Mine, Montana. Arrow locates ground water seeps (water sample OW-11) just over the Dietz #1 coal bed.

Fig. 4. Field infiltration test being performed on spoils at Bighorn Mine, Sheridan, Wyoming.

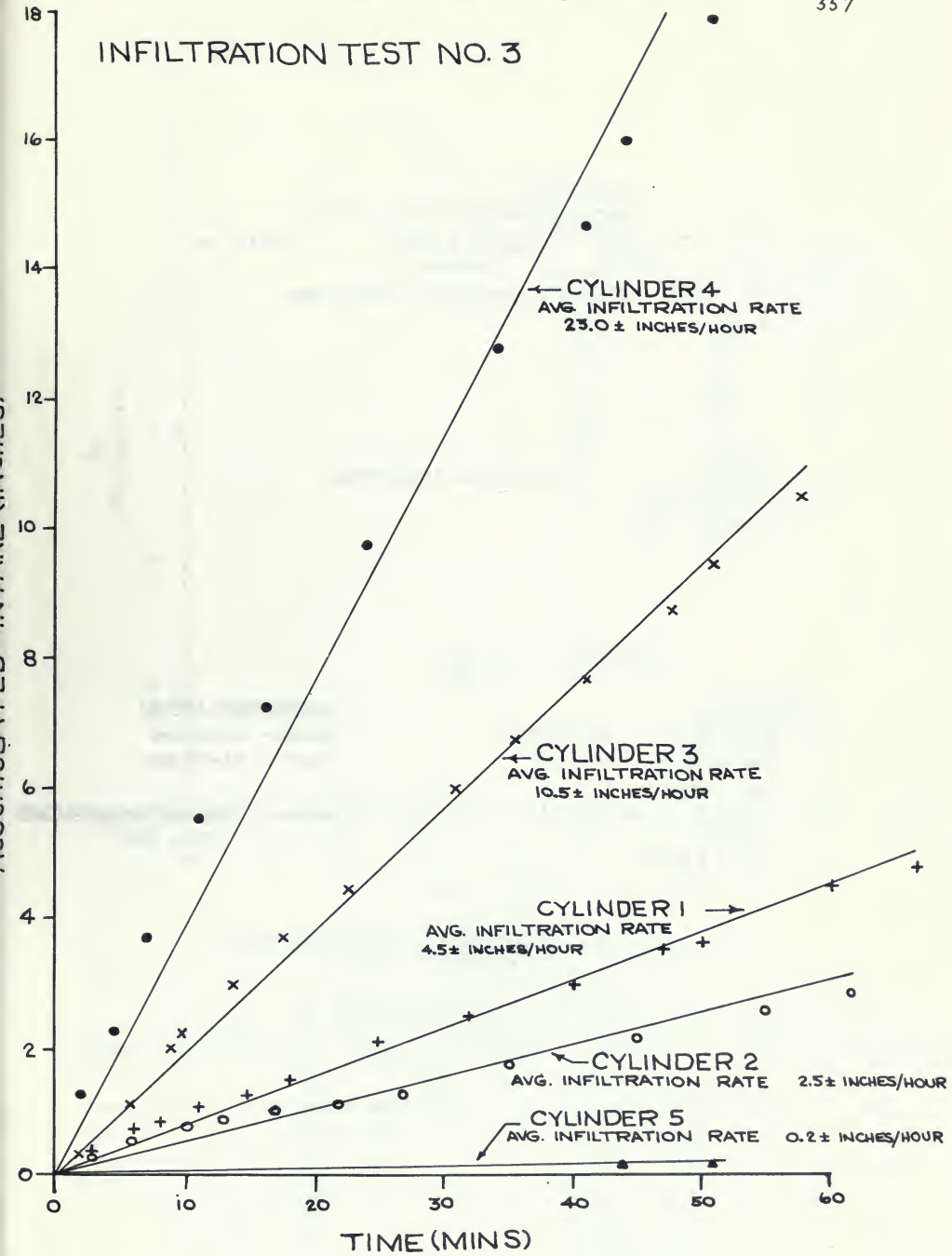
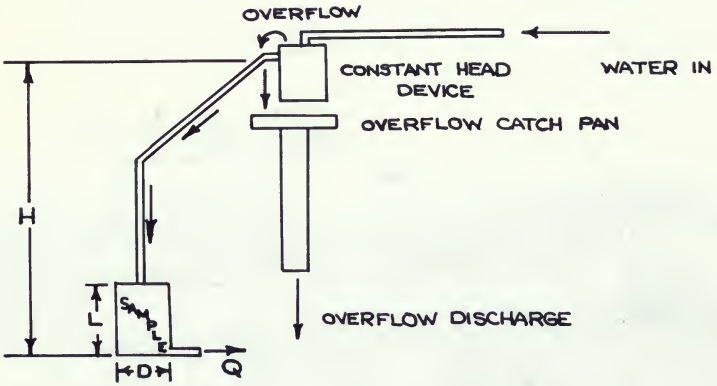


Fig. 5. Field infiltration test results for spoils near Acme, Wyo.



THEORY: $K = \frac{QL}{AH}$

PARAMETERS:

K = PERMEABILITY GAL/DAY/FT²

Q = DISCHARGE GAL/DAY

L = 7 IN = 0.583 FT

$A = \frac{(.5\,FT)^2 \pi}{4} = 0.1963\ FT^2$

H = 34 IN = 2.83 FT

CONVERSION UNITS:

500ML = 0.1315 GAL

1 DAY = 86400 SEC

$Q_{GAL/DAY} = \frac{(.1315\,GAL)(86400\,SEC/DAY)}{TRIAL\ SEC}$

$K = \frac{(Q)(0.583)}{(0.1963)(2.83)} = 1.05Q\ GAL/DAY/FT^2$

Fig. 6. Sketch of laboratory permeability apparatus.

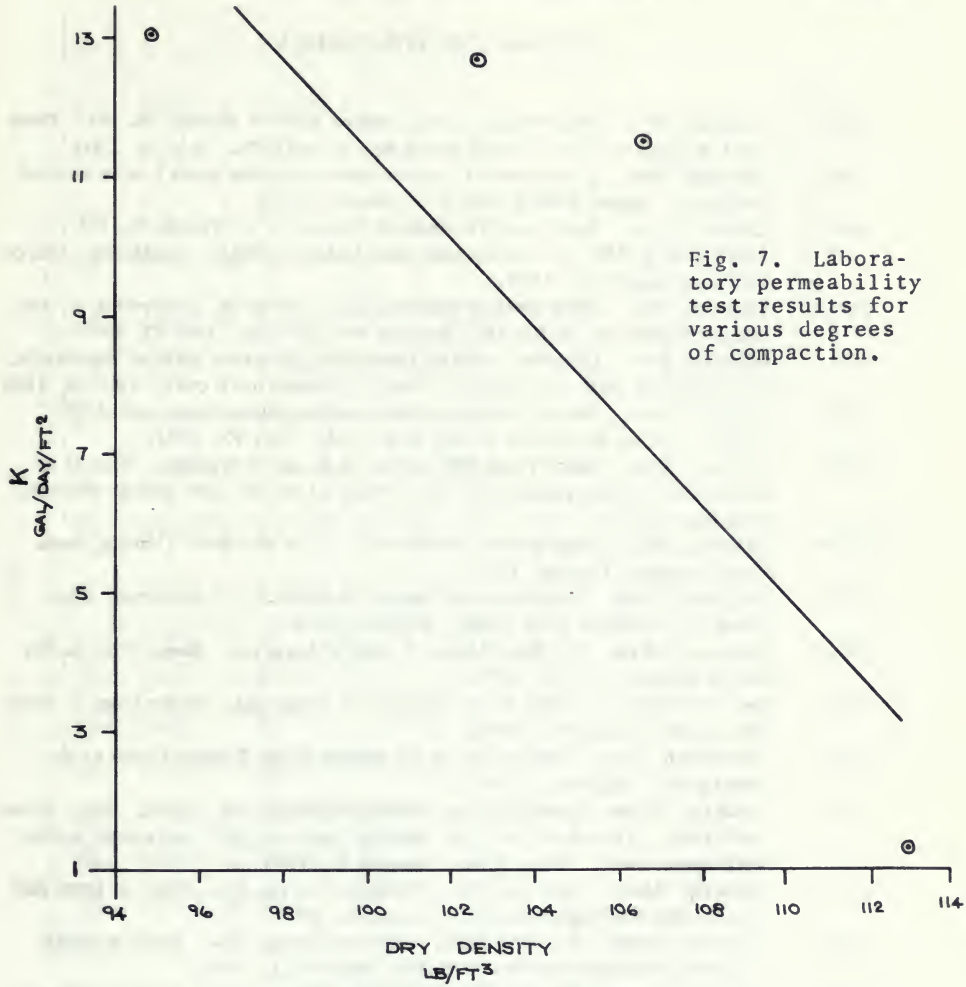


Fig. 7. Laboratory permeability test results for various degrees of compaction.

MIXED SAND AND GRAVEL, SAMPLE OW-17S.

SAMPLE	STYLE OF COMPACTION	DENSITY DATA		PERMEABILITY DATA		
		DRY WEIGHT (LB)	DRY DENSITY (LB/FT³)	TIME (SEC/500 ML)	Q (GAL/DAY)	K (GAL/DAY/FT²)
MIXED SAND AND GRAVEL	NONE	10.8	94.8	1-915 3-918 2-920 4-917	12.4	13.02
	5 DROPS	12.2	106.6	1-1035 3-1028 2-1030 4-1035	11.0	11.55
	10 DROPS	11.8	102.6	1-945 3-952 2-950 4-950	12.0	12.6
	15 DROPS	12.9	113.1	1-9000 3-8942 2-8975 4-9030	1.27	1.33

EXPLANATION FOR TABLE 1

OW-1	Gillette, Wyo. New 850 gpm well 2 miles NNW of Wyodak N. Pit. Used for I-90 construction. Depth about 90', in coal (?). July 22, 1974.
OW-2	Gillette, Wyo. Ground water in open pond in scoria pond 1 mile east of Belle Ayr Mine, AMAX Coal Co. March, 1974.
OW-3	Gillette, Wyo. Stock well at windmill 1 mile N. of Wyodak N. Pit. Shallow well (100' ?) in alluvium, and bedrock (shale, sandstone, and/or clinker (?). July 22, 1974.
OW-4	Gillette, Wyo. Stock well at windmill 1 1/2 miles W. of Wyodak N. Pit, about 1/2 mile N. of Rt. 16. Shallow well (100'?). July 22, 1974.
OW-5	Gillette, Wyo. Domestic well of Dale Mills, 2 miles NNW of Wyodak N. Pit. Shallow well, probably 50' deep in clinker over coal. July 22, 1974.
OW-6	Gillette, Wyo. Seeps from prominent bedding plane in center of 55' cliff of coal on N. side of N. pit at Wyodak. July 23, 1974.
OW-7	Gillette, Wyo. Seeps from SW corner of S. pit at Wyodak. Seep is at contact of 10" clay parting 35' above base at the 85' coal bed at Wyodak. July 23, 1974.
OW-8	Gillette, Wyo. Seep in NW corner of S. pit at Wyodak. Coming from under spoils. July 24, 1974.
OW-9	Sheridan, Wyo. Monarch strip mines, 3 miles N. of Monarch, Wyo. Pond in abandoned strip mine. July 31, 1974.
OW-10	Sheridan, Wyo. Big Horn Mine, S. end of Main pit. Seeps from under active dump. July 31, 1974.
OW-11	Decker, Mont. Decker Coal, SW face of active pit. Seeps from 5' over top of coal. August 1, 1974.
OW-12	Kleenburn, Wyo. Fish ponds in old dumps along Tongue River at Boy Scout park. August 1, 1974.
OW-13	Colstrip, Mont. Rosebud Mine, Western Energy Co. Mont. Bur. Mines Well #S-1, 1/3 mile S. of R. R. loading tipple in 1968 reclaimed spoils. Well depth = 45'. Static = 44'. August 21, 1974.
OW-14	Colstrip, Mont. Rosebud Mine, Western Energy Co. Pond at West end of old 1968 Burlington Spoils. August 21, 1974.
OW-15	Colstrip, Mont. Rosebud Mine, Western Energy Co. Pond in spoils in semi-reclaimed bulldozed spoils. August 21, 1974.
OW-16	Colstrip, Mont. Rosebud Mine, Western Energy Co. Pond in bottom active pit. August 21, 1974.
OW-17	Colstrip, Mont. Rosebud Mine, Western Energy Co. Pond in Pit #3, a deep ground water pit 2/3 mile N. of tipple. Has panfish. Old unreclaimed spoils. August 21, 1974.
OW-18	Colstrip, Mont. Big Sky Mine, Peabody Coal Co. Pond fed by seeps at bottom of pit, coming from ground water in Rosebud coal seam. August 22, 1974.
OW-19	Colstrip, Mont. Big Sky Mine, Peabody Coal Co. Pit in west end, probably ground water recharged. August 22, 1974.
OW-20	Colstrip, Mont. Big Sky Mine, Peabody Coal Co. Pond in spoils 300 yds. NE of S. end of W. highwall. Could be mostly rain runoff. August 22, 1974.

Table 1. Water quality data for 20 water samples.

Substance (MG/L)	Maximum Recommended drinking water limits g	SAMPLE OW-1	OW-2	OW-3	OW-4	OW-5	OW-6	OW-7	OW-8	OW-9	OW-10	OW-11	OW-12	OW-13	OW-14	OW-15	OW-16	OW-17	OW-18	OW-19	OW-20
Total Dissolved Solids	1500	5310[y]	1012	852	2312[x]	1222	1626[x]	2616[x]	2016[x]	1178	4096[x]	4732[y]	1000	2994[x]	2954[x]	5182[y]	1168	4994[y]	1510[x]	2008[x]	1594[x]
Volatile Dissolved Solids		676	148	184	282	198	286	452	330	152	90	330		490	558	908	454	878	364	442	270
Total Suspended Solids		5	10	9	3	3	14	11	35	14	8	2	8								
Volatile Suspended Solids			10																		
Total Hardness		2554	589	709	1327	727	945	1463	1027	700	982	1473	536	2063	1809	3045	627	2982	909	1400	900
Carbonate Hardness		99	195	295	166	156	446	311	681	107	566	438	178	644	176	188	154	149	271	533	
Non-Carbonate Hardness		2455	394	414	1161	571	499	1152	346	593	416	1035	358	1419	1633	2857	473	2833	638	867	
pH		7.91	8.0	7.84	7.62	7.64	7.45	7.48	7.07	9.00	7.10	8.56	8.64	7.73	8.26	7.83	8.02	7.92	7.72	7.77	8.37
Alkalinity (Phenolph'n)			0							6		14	10								2
Alkalinity (Met. Orange)		99	195	295	166	156	446	311	681	107	566	438	178	644	176	188	154	149	271	533	83
Turbidity (J.U.)		<4	4	26	4	4	16	16	22	12	<4	16	4								
Spec. Conductance		4100	1000	1300	2200	1350	1900	2750	2600	1500	4700	5000	1300	2100	2700	3200	1300	3500	1600	2150	1600
Calcium (Ca)	200	431[x]	149	156	319[x]	182	230[x]	316[x]	234[x]	82	182	141	52	336[x]	166	364[y]	92	261[x]	138	152	126
Magnesium (Mg)	125	360[x]	53	78	129[x]	66	90	164[x]	108	121	128[x]	272[x]	99	298[y]	339[x]	520[y]	96	566[y]	137[x]	248[x]	142[x]
Sodium (Na)	200 b	190	50	22	111	29	130	175	295[x]	93	850[y]	900[y]	98	74	88	170	44	120	91	110	74
Potassium (K)	c	255	24	5	40	31	18	18	17	18	33	21	17	11	14	17	7	20	7	8	12
Iron (Fe)	1.0	0.13	0.06	0.16	0.13	0.13	0.13	0.12	0.24	0.10	0.06	0.08	0.03	0.06	0.12	0.08	0.06	0.08	0.08	0.1	0.12
Manganese (Mn)	.05	0.51[z]	0.05	0.30[y]	0.40[y]	0.05	0.09[x]	<0.05	0.58[z]	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Aluminum (Al)	c	0.10		0.10	0.18	0.18	0.08	0.19	0.09	0.08	0.42	0.09	0.15	0.11	0.12	0.15	0.13	0.12	0.11	0.11	0.18
Chloride (Cl)	250	17	4.5	1	5	3	1	102	0.5	11	2	1	16	1	14	13	4	11	2	1	9
Sulfate (SO_4)	250	3085[z]	500[x]	488[x]	1379[y]	639[x]	818[y]	1355[y]	968[y]	719[x]	2345[y]	2909[z]	546[x]	1700[y]	1800[y]	3100[z]	588[x]	2750[z]	840[y]	1050[y]	850[y]
Silica (SiO_2)	c	44	17	16	26	31	21	23	22.5	2.4	19.6	8.1	2.4	21	11	10	16	9	18	15	5
Nitrate (N)	20	4.4	0.10	3.3	3.7	4.4	5.2	5.2	2.6	0.7	1.3	8.8	1.0	2.2	<0.10	<0.1	63[y]	<0.1	21[x]	2	<0.1
Orthophosphate (PO_4)	c	0.1	<0.1	0.1	0.5	0.5	0.5	0.3	0.1	0.4	0.3	0.4	0.4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Total Phosphate (PO_4)	c	1.3	0.1	0.5	0.9	1.8	1.8	0.9	1.3	0.4	0.4	2.7	0.5	1.8	0.7	0.9	0.6	0.3	0.7	0.9	0.3
Flouride (F)	1.5	1.31		1.00	1.31	1.25	1.15	1.36	1.05	1.20	1.20	2.02[x]	0.52	0.6	0.3	0.95	0.05	0.88	0.6	0.68	0.2
TRACE ELEMENTS:																					
Antimony	.05										nt	nt									
Arsenic	.05 a										<0.01	<0.01									
Barium	1.00 a										< 0.5	< 0.5									
Boron	20. d										1.3	1.7									
Bromide	e										-f-	-f-									
Cadmium	.01 a										.017[x]	.014[x]									
Chromium (Hexavalent)	.05 a										<.006	<.006									
Cobalt	e										.026	.032									
Copper	1.0										.006	.005									
Cyanide	0.2 a										nt	nt									
Germanium	e										-f-	-f-									
Iodide	e										-f-	-f-									
Lead	.05 a										<.001	<.01									
Lithium	e										.43	.36									
Mercury (Dissolved)	.005 a										nt	nt									
Molybdenum	e										.04	.018									
Selenium	.01 a										< .01	< .01									
Silver	.05 a										nt	nt									
Strontium	e										1.7	1.7									
Uranium	e										-f-	-f-									
Vanadium	e										.01	<.01									
Zinc	5.0										.015	.009									

see p.360 for explanation of OW# entries

Notes

a - Mandatory Limits of U. S. P. H. S. (1962)
b - Irrigation water should have 300 ppm sodium.
c - Not harmful to humans dissolved water.
d - Irrigation water should have 3 ppm boron.
e - Maximum limits unknown.
f - No measurable amounts found; lower limit of test unknown.
g - From Davis and DeWeist (1966, p. 121).
nt- not tested.

x - greater than recommended drinking water limits.
y - 3 x greater than recommended drinking water limits.
z - 10 x greater than recommended drinking water limits.

Table 1

LATERAL AND VERTICAL VARIATIONS IN SULFUR AND TRACE ELEMENTS IN COAL: COLSTRIP FIELD, MONTANA

Robert A. Chadwick, Ray A. Woodriff, Ronald W. Stone, and Catheryn M. Bennett*

SUMMARY OF ANALYSES

Concentrations of sulfur and 14 selected trace elements in the Rosebud and McKay coal seams from Western Energy Company controlled properties in the Colstrip field, Montana, have been determined and their distribution plotted. The study, conducted by Montana State University personnel under a contract from Montana Power Company, contributes to an evaluation of possible air pollution hazards when mine-site power plants begin operations.

Sulfur content of the coal (oven dry basis) averages 1.07% in the Rosebud and 1.87% in the underlying McKay coal seam, based on proximate analyses from 221 and 228 cored drill holes penetrating the respective seams. Holes are distributed across a 12 by 6 mile area of the Colstrip field; most of them penetrate both coal seams.

Trace elements, analyzed (except for fluorine) by furnace atomic absorption, were determined from air dried, pulverized coal samples representing cores from 49 drill holes penetrating the Rosebud seam and 26 in the McKay. Altogether, 100 samples were analyzed; in five holes several vertical increments of the coal seam were run separately. Results, converted to the oven dry (moisture free) basis, are averaged in Table 1. In the Table, each drill hole is given equal weight.

VERTICAL DISTRIBUTION

In five drill holes near the present mine workings in the eastern part of the field (Fig. 1), the cores were separated into a number of vertical increments, mostly 5 feet each. Each increment was analyzed separately for trace elements. Thus changes in element content from top to bottom of each seam, and from the overlying (Rosebud) seam to the underlying (McKay) seam could be studied. In a larger number of holes, sulfur content was determined by one-foot vertical increments.

The coal seams occur in the Tongue River member of the Fort Union Formation of Paleocene age (3). In the Colstrip field, the Rosebud seam is 20 to 29 feet thick, averaging 25 feet. Beneath it and separated from it by a zone of sandy shale, sandstone, and clay, is the 7 to 9 feet thick McKay seam. This

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TABLE 1. COAL TRACE ELEMENT ANALYSES: AVERAGES

Element	Analyses in parts per million (ppm) of whole coal, moisture free basis	
	Rosebud Seam (49 holes)	McKay Seam (26 holes)
Antimony	0.61	0.46
Arsenic	6.02	6.13
Beryllium	0.44	0.45
Cadmium	0.129	0.139
Chromium	5.37	5.30
Copper	12.5	14.6
Fluorine	51.	19.
Germanium	2.64	3.98
Lead	8.8	6.4
Manganese	66.1	22.4
Mercury	0.20	0.22
Nickel	37.3	26.5
Selenium	1.29	0.73
Zinc	49.6	15.8

intervening sandy shale unit is 10 to 30 feet thick near the mined area in the eastern part of the district, but thickens to as much as 115 feet in the western portion of the field in sec. 5, T 1 N, R 40 E (see Fig. 1). Overburden above the Rosebud seam is principally sandstone, and beneath the McKay there are interbedded units of clay, shale, and sandstone. The entire sedimentary sequence dips gently south and southeast, but this overall attitude is modified by gentle folds and flexures and perhaps some faults of displacement not exceeding several tens of feet.

The McKay seam analyzes almost twice as high in sulfur as does the Rosebud, according to drilling information to date. Furthermore, in many drill cores, sulfur is concentrated near the bottom of each coal seam, and in some cores near the top also (1, 2). In many holes, sulfur is concentrated in the basal foot of the seam; in other holes a few feet above the base, and in a lesser number of holes at the top in addition to or instead of at the base. An averaging of sulfur content in 45 drill holes analyzed in increments of one foot in the McKay seam (2) is listed in Table 2.

TABLE 2. SULFUR DISTRIBUTION VERTICALLY IN MCKAY COAL SEAM

Top one foot of seam	2.22% S (dry basis)
Intermediate interval (5-7')	1.66
Bottom one foot of seam	3.51

The enrichment of sulfur in the basal footage of the seams relates to visible concentrations of pyrite (FeS_2) sheets in vertical fractures in the coal. Whether organic sulfur is also enriched near the base of seams is not known; sulfur in one-foot vertical increments was not analyzed by forms. Through the district in general, where total sulfur in a drill hole is high, pyritic sulfur is quite high and appears to account for most of the sulfur enrichment.

The pyrite sheets are roughly disc-shaped, having diameters of 1 to 4 cm. and thicknesses of 1/4 to 1 mm. Mine face observations indicate that the sheets are principally vertically oriented, though in various azimuth directions. In places at the base of a seam, the discs flatten out to become parallel to the basal contact. Since the pyrite sheets occur in fractures, they evidently were deposited after the coal had been solidified sufficiently to permit fracturing (2). Perhaps waters percolating through the seam deposited the pyrite by reduction of sulfate or native sulfur either inorganically or by bacterial activity. Iron may have been derived from adjacent shale or clay beds. A smaller amount of pyrite occurs throughout the coal seams as microscopic blebs, spindles, and cubic grains 5 to 50 microns in size; such pyrite may represent an earlier, perhaps syngenetic, generation of deposition.

Certain trace elements exhibit a marked enrichment at or near the base of seams similar to that of sulfur. Five holes penetrating the Rosebud seam, the southernmost three of which also cut the McKay (Fig. 1) have been analyzed in vertical increments for the 14 trace elements listed in Table 1. According to studies to date(1, 2) the following elements are markedly enriched at the base, and in some holes at the top, of seams: antimony, arsenic, beryllium, cadmium, mercury, nickel, and selenium. The following elements exhibit a tendency to concentrate similarly in at least some holes: chromium, copper, germanium, and zinc. Figure 2 illustrates the relationships for selected elements in two drill holes in sec. 18, T 1 N, R 42 E which penetrate the Rosebud seam. In these holes, sulfur, arsenic, beryllium, mercury, and to a lesser extent nickel are appreciably enriched in the basal two feet and five feet of the respective coal seam cores.

The elements fluorine, lead, and manganese show no relation to the top or base of seams, nor do they correlate with ash content.

In general, elements having affinity for sulfur (the so-called chalcophile group) are those showing marked enrichment at the bottom of seams along with sulfur. Nickel may occur as an atomic substitution for iron in the pyrite lattice; arsenic, copper, zinc, mercury, cadmium, and antimony may be present as inclusions, intergrowths, or replacement bodies of other sulfide minerals within pyrite. Some elements may be associated with organic sulfur. Beryllium concentration at the base of seams is difficult to explain since this element has high ionic potential and is generally related to the organic fraction of coals; however, enrichment of Be in the heavy (pyritic) fraction of washed coal has been noted by others(4).

LATERAL DISTRIBUTION

Lateral variations of sulfur and trace element content within each coal seam across the Colstrip field do not produce patterns as well defined as do vertical variations within a seam. Unfortunately, the spacing between holes (1000 ft centers minimum) is such that localized variations in sulfur or trace element content, if present, would not be detected.

Sulfur is consistently higher in the McKay seam than in the Rosebud; however, within each seam, sulfur content is higher in certain portions of the field than in others.

High-sulfur areas, especially in the Rosebud seam (over 1.8% S, dry basis), tend to cluster near a major monoclinal flexure or "rollover" in the geologic strata near the west edge of R 41 E. The elevation of the base of the Rosebud seam drops abruptly toward the southeast along this flexure (Fig. 1). More detailed drilling is needed to evaluate the extent and significance of this relationship. Since much pyritic sulfur is evidently of post-solidification origin, enrichment may be related to circulation of waters along fractured and/or flexed portions of the Fort Union strata.

Trace element content varies laterally along a seam, but the significance is uncertain because of the wide spacing between drill holes. Except for the five holes in the southeastern part of the field analyzed in vertical increments, each analysis represents the entire thickness of a coal seam.

Figure 1 outlines areas of the Rosebud seam which contain "anomalously high" quantities of various trace elements. An "anomalous area" is plotted if analyses for an element are at least double the mean in each of two or more adjacent drill holes. Elements satisfying this criterion are: beryllium (>0.88 ppm); germanium (>5.28 ppm); lead (>17.6 ppm); nickel (>74.6 ppm); and selenium (>2.58 ppm).

Similarly, analyses of an element which are, in two or more adjacent holes, at least 1 1/2 times its mean may be plotted. On such a map (not illustrated), two areas stand out: (1) secs, 2 and 3, T 1 N, R 40 E, which contain highs in As, Cu, Sb, and Zn as well as Be; and (2) secs. 3 and 4, T 1 N, R 41 E, where fields of high Ge, Pb, Se, and Zn partly overlap. The former area coincides approximately with a synclinal fold axis. However, many trace element highs do not appear to correlate with structural features of the coal seam sequence.

Fewer anomalous areas can be outlined in the McKay seam, partly because samples cover only 26 holes rather than 49. Where high values are present, they generally do not coincide with highs in the Rosebud seam for the same element. An exception is lead, which is high in both seams in secs. 3, 4 and 5, T 1 N, R 41 E.

Mercury is one of the most uniformly distributed elements. All values (in both seams) range between 0.09 and 0.35 ppm.

Geochemical controls over lateral distribution of trace

elements in the coal seams are unclear on the basis of present studies. To investigate this problem further, sampling should be conducted on a much closer spacing in selected areas utilizing mine faces as well as drill cores. Results of analyses should be keyed to visual observation of coal seam variations such as sulfide and silicate mineralogy, maceral type, clay partings, faults, joints, and sharp folds. The present study of vertical distribution of trace element and sulfur content indicates that variations are significant over short distances and are probably dependent on delicate changes in the geological and chemical environment, particularly those involving processes which post-date consolidation of the coal.

ANALYTICAL PROCEDURE

Sulfur was analyzed by Commercial Testing and Engineering Co. of Chicago and Northern Testing Laboratories of Billings. These laboratories utilize standard ASTM procedure. Coal samples from the field are weighted and, for trace element studies, pulverized and dried by a flow of air at approximately room temperature and in the presence of $CaCl_2$ dessicant. Total sulfur content is determined by the bomb washing gravimetric method. Forms of sulfur (pyritic, organic, and sulfate) are distinguished using ASTM procedure.

Trace element values were determined in the Montana State University Chemistry Department Laboratory using a constant temperature furnace atomic absorption spectrochemical technique designed by R. A. Woodriff of that department. Many of the elements analyzed are volatile and difficult to determine spectrographically because of almost immediate vaporization and escape from the analyzing chamber. The atomic absorption furnace utilized by this study avoids this problem and allows more accurate determination of many volatile elements.

The furnace is so constructed that it confines the gaseous sample to the light path for a much longer time than is possible with conventional atomic absorption techniques. Also, the dilution, absorption, and turbulence inherent in flame gases is eliminated. For all the elements analyzed except mercury, the coal is digested in a mixture of nitric and hydrochloric acid in an acid-digestion bomb.

The solution is placed in a small graphite cup and inserted through the sidearm into the furnace. Argon enters at the ball joint and washes the oxygen off the sample as it is inserted. The cup sits near the optical path, and the sample evaporates and enters the light beam. Argon pressure prevents any appreciable leakage backwards, and the tube is long enough so that the last of the sample evaporates before the first leaves the tube. Since the sample is confined to a long, narrow light path by hot walls, the sensitivity is very high. Sensitivities obtained are on the order of 10^{-10} to 10^{-12} g for elements tested (6). Working detection limits are listed in Table 3.

To analyze mercury, coal is burned rather than dissolved, and mercury in the vapor is concentrated on a gold plated graphite cup (5). The cup is inserted into the furnace as described above.

TABLE 3. DETECTION LIMITS

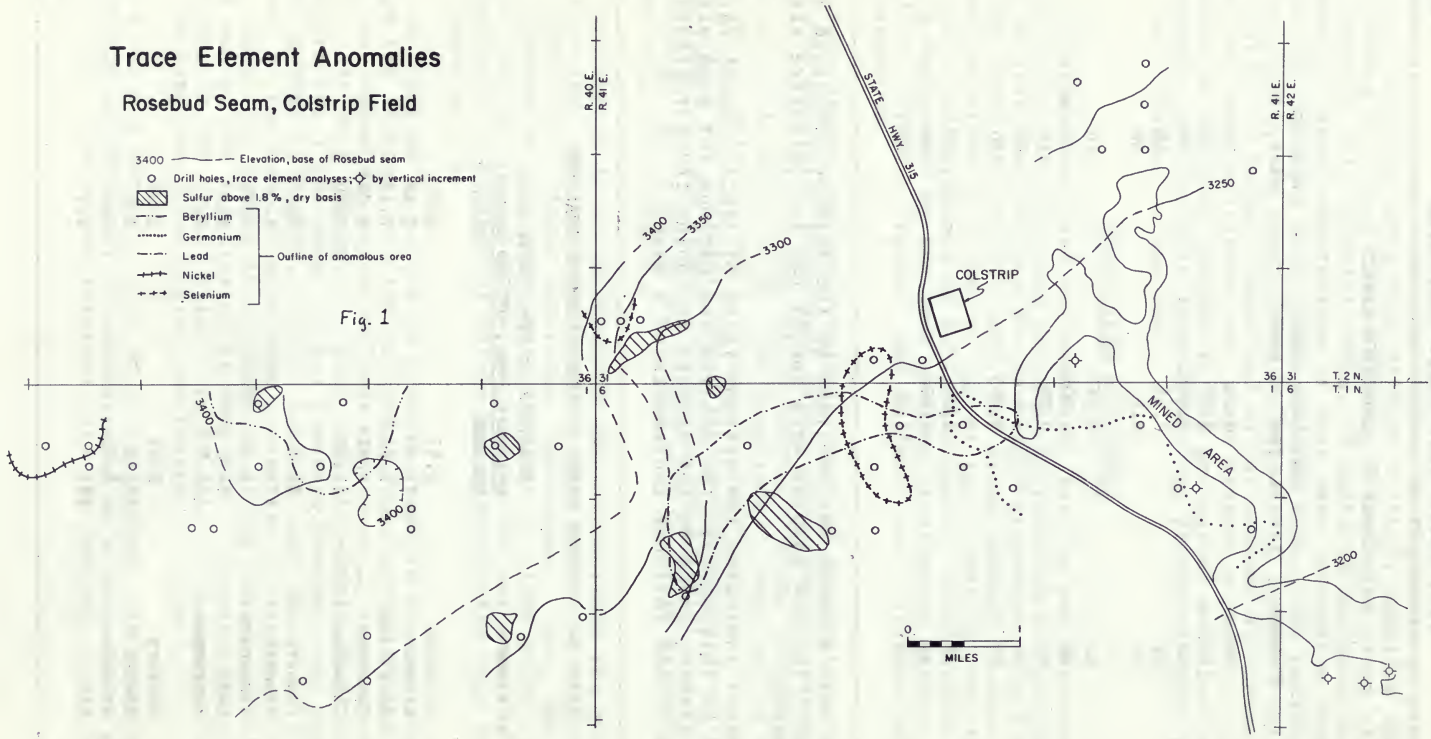
Element	Detection limit in ppm of coal	Aliquot size, µl
As	0.13	20
Be	0.03	50
Cd	0.0012	10
Cr	0.25	50
Cu	0.5	50
Ge	0.36	50
Hg	0.005	20 (mg.)
Mn	0.75	10
Ni	2.5	100
Pb	0.063	10
Sb	0.02	50
Se	0.19	50
Zn	2.5	50

The only element not analyzed by the furnace technique is fluorine. Fluorine samples were run by the ion selective electrode method.

Table 4 indicates the extreme range of trace element values obtained by this study. The minimum and maximum for each element is listed, based on 100 samples including those representing 2 to 5 foot vertical increments of a seam.

TABLE 4. EXTREME RANGE OF TRACE ELEMENT ANALYSES

Element	Analyses in ppm, whole coal moisture free, of 100 samples	
	Maximum	Minimum
Antimony	2.55	<0.07
Arsenic	21.30	0.68
Beryllium	1.91	0.11
Cadmium	1.510	0.021
Chromium	31.20	<0.40
Copper	40.3	4.6
Fluorine	173.	4.
Germanium	16.35	<0.10
Lead	94.0	1.3
Manganese	404.5	6.7
Mercury	0.61	0.08
Nickel	163.5	1.6
Selenium	5.62	<0.07
Zinc	361.	<1.7


Trace Element Anomalies
Rosebud Seam, Colstrip Field
3400 Elevation, base of Rosebud seam
Drill holes, trace element analyses; by vertical increment
Sulfur above 1.8 %, dry basis
Beryllium
Germanium
Lead
Nickel
Selenium
Outline of anomalous area
Fig. 1
R. 40 E.
R. 41 E.
R. 41 E.
R. 42 E.
STATE HWY. 315
COLSTRIP
MINED AREA
3400
3350
3300
3250
3200
36
31
1
6
T. 2 N.
T. 1 N.
0
1
MILES

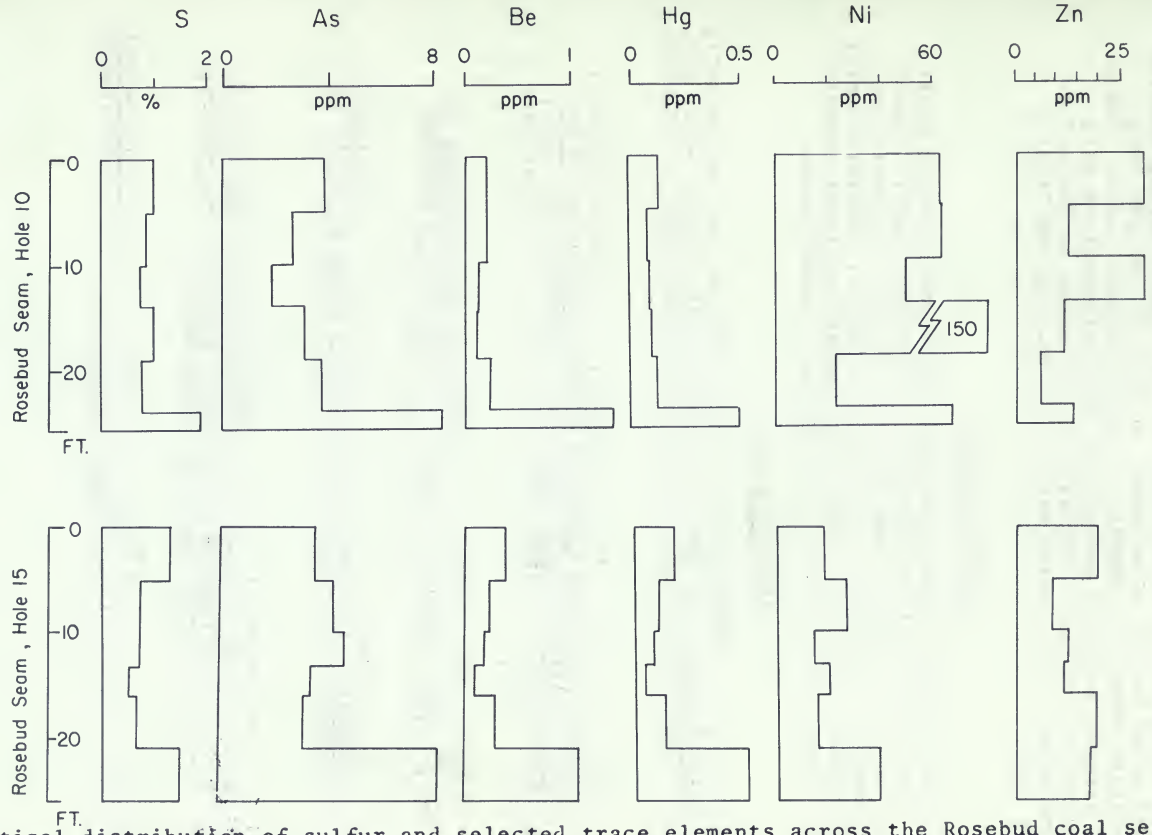


Fig. 2. Vertical distribution of sulfur and selected trace elements across the Rosebud coal seam. A number of elements are enriched in the basal portion of the seam. Trace element analyses are based on the air dried sample. For each hole, vertical increments sampled, in feet, are: Hole 10: 0-5, 5-10, 10-14, 14-19, 19-24, 24-25.5; Hole 15: 0-5, 5-10, 10-13, 13-16, 16-21, 21-26.

Trace element analyses, originally obtained as parts per million of air dried coal, are converted to the oven dry (moisture free) basis by correcting for loss of weight during heating of the air dried sample in an overn at 110° C. Weight loss, fairly uniform among the samples tested, averages 8.26%. Since the coal samples analyzed average 26.3% total moisture with little spread in values, conversion of the means in Table 1 to the "as received" basis would entail multiplying the Table 1 values by .737.

ACKNOWLEDGMENTS

The trace element study described above was financed under a contract to Montana State University by Montana Power Company. Laboratory and office space was furnished by Montana State University Chemistry and Earth Sciences Departments. Western Energy Company supplied drill hole logs and proximate analysis reports. The aid of these organizations is gratefully acknowledged.

LITERATURE CITED

1. Chadwick, R. A., Bennett, C. M., Woodriff, R. A., and Bennett, R., Trace Elements in Eastern Montana Coal (abst.) Geol. Soc. America, Rocky Mtn. Sec., Abstracts With Programs, p. 432-433. 1974.

2. Chadwick, R. A., Rice, R. C., Bennett, C. M., and Woodriff, R. A., Sulfur and Trace Elements in the Rosebud and McKay Coal Seams, Colstrip Field, Montana. Montana Geol. Soc., Energy Resources of Montana (With Emphasis on Natural Gas and Coal). 1975.

3. Matson, R. E., and Blumer, J. W., Quality and Reserves of Strippable Coal, Selected Deposits, Southeastern Montana. Mont. Bur. Mines and Geol. Bull, 91, 135p. 1973.

4. Ruch, R. R., Gluskoter, H. J., and Shimp, N. F., Occurrence and Distribution of Potentially Volatile Trace Elements in Coal. Illinois Geol. Surv. Envtl. Geol. Notes, No. 72, 96 p. 1974.

5. Siemer, D. and Woodriff, R. A., Application of the Carbon Rod Atomizer to the Determination of Mercury in the Gaseous Products of Oxygen Combustion of Solid Samples. Analytical Chem., v. 46, No. 4, p. 597-598. 1974.

6. Woodriff, R. A., Stone, R. W., and Held, A. M., Electrothermal Atomization for Atomic Absorption Analysis: Appl. Spectroscopy, v. 22, No. 5, pt. 1, p. 408-411. 1968.

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